

Australian Government

COVID-19 TESTING AND RESPONSE Strategies in regional and Remote indigenous communities: Key messages for health services

BE COVIDSAFE

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Regional and remote Indigenous Australian communities have the potential to be severely impacted by COVID-19 outbreaks. Our modelling aims to help inform responses by examining a range of scenarios for disease transmission, case finding, quarantine, testing and lockdown.

Key messages:

- An uncontained outbreak in a remote community of 1,000 people will spread rapidly, due to overcrowded housing, close mixing in groups, and between interconnected households.
- Early case detection and prompt response are crucial, as it is likely that multiple secondary cases will be present in the community by the time a single index case is identified.
- Extensive quarantine of close contacts defined by extended household membership can constrain the initial (2 month) outbreak **reducing peak infection prevalence from 60-70% to around 10%**. However, infections resurge when community mixing resumes and the **overall community attack rate over a period of several months exceeds 80%** in modelled scenarios.
- It is reasonably anticipated that a proportion of cases will not present for testing either because of mild symptoms, no symptoms, or fear/stigma. Routine testing of all individuals on entry and exit from quarantine in this context, as recommended in national guidelines, assists case finding and reduces the risk of ongoing infections in the community.
- In addition to the above measures, lockdown of non-quarantined households for 14 days in community is a highly effective strategy for epidemic control and reduces overall testing requirements by limiting the likelihood of successive waves of infection, even if there is a delay of several days to initial response.
 Peak prevalence of the initial (1 month) outbreak can be constrained to less than 5%, and the final attack rate to less than 10% in modelled scenarios.
- Compliance with lockdown must be at least 80-90% however, or epidemic control will be lost, with almost no benefit observed at lower levels of compliance.
- The benefits of lockdown are greatest in communities of 1,000 or more people but are still observed in communities of size 500. In smaller communities of 100 people, a large proportion of the population is likely to be interconnected through household membership and placed into quarantine as part of initial response, minimising additional impacts of lockdown.

Model findings

Importance of prompt case finding

We assume a scenario in which an initial case is 'silently' imported into a community of 100, 500, 1,000 or 3,500 people and detected on presentation to the health service. Given the potential for infection spread in remote communities, by the time this individual is detected the true number of cases could be up to ten times higher (see Table 1, below). This number logically increases if the initial response is delayed until more than one case is identified.

Table 1: Impact of delays to case finding. Scenarios are shown for a range of community sizes (horizontal rows), reporting active case and cumulative case numbers in that community by the time the initial one, two or five cases are identified. Medians are reported, with interquartile ranges, from 100 simulations.

Population size	One case identified		Two cases	s identified	Five cases identified		
	Active Cumulative cases cases		Active cases	Cumulative cases	Active cases	Cumulative cases	
100	9 (5, 16) 32 (15, 47)		18 (11, 25)	52 (38, 65)	37 (28, 46)	84 (71, 90)	
500	7 (2, 15)	29 (9, 55)	20 (12, 30)	73 (50, 104)	48 (37, 63)	162 (134, 207)	
1000	6 (3, 14)	27 (10, 59)	19 (11, 27)	72 (46, 100)	50 (33, 68)	184 (131, 235)	
3500	7 (4, 11)	22 (9, 42)	18 (11, 25)	66 (44, 105)	49 (35, 67)	187 (144, 247)	

Impact of quarantine on initial outbreak control

We assess the impact of quarantining identified contacts of the index case according to alternative ascertainment strategies (Figure 1).

Figure 1: Definitions of contacts to be quarantined. The household-based definition of contacts involves quarantine of the index case's immediate and extended households defined by family group membership. The alternative definition of contacts relies on active contact tracing over the preceding 2 days, including members of any households in which the index was resident during that 2-day period. We also consider extending measures to casual community contacts over this period.



Contact definition based on extended household membership is the most effective strategy (Figure 2, left panels), involving a large number of people from closely interconnected households, associated with high transmission risk. Testing on entry into quarantine is routine, and an effective case finding strategy. Clearance testing (Figure 2, lower panels) has little impact on the epidemic course in the model, *based on the assumption that quarantined individuals are perfectly isolated from both household and community members and not at ongoing infection risk.*

Figure 2: Contact tracing strategies: household-based contact tracing (left) versus history-based contact tracing (for the prior 2 days, at right). Epidemic curves for a community of 1000 people are shown, comparing the household-based tracing strategy (at left) with the history-based tracing (for the prior 2 days) strategy (at right). Given the assumption of 'perfect' quarantine, clearance testing adds little to epidemic constraint, assuming that entry testing has already enhanced case finding efforts.



Table 2 provides additional summary information on epidemic outcomes and public health response measures for the scenarios in Figure 2. A review of cumulative case numbers in each epidemic clarifies that while the first wave is blunted by the initial epidemic response, ongoing waves of infection result in a high proportion of the population becoming infected in almost all cases. Implementation of extended household quarantine with clearance testing has the greatest impact on final size but requires a large number of people to be quarantined over an extended period and very high testing rates.

Table 2: Contact tracing and testing strategies: impact on size of outbreak (total cumulative cases), quarantine person-days, and total tests performed during outbreak. Figures in the table are medians, with interquartile ranges.

Strategy	No d	clearance tes	ting	Clearance testing undertaken				
	Total cumulative cases	Quarantine person- days (first year)	Total tests performed during outbreak (first year)	Total cumulative cases	Quarantine person- days (first year)	Total tests performed during outbreak (first year)		
No response	999 (999-999)	N/A	447.0 (435.5, 458.0)	999	N/A	N/A		
Quarantine of immediate household contacts (with case isolation)	922.0 (907.5, 936.5)	29595.5 (28101.5 - 31175.0)	1957.5 (1867 - 2027)	922.5 (905.0, 933.0)	22500.5 (21469.0 - 23306.0)	7526.0 (7336 - 7743)		
Quarantine of extended i.e. all household contacts (with case isolation)	of 831.5 86825.0 e. (751.0, (70334.5 - ld 871.0) 97662.5) ith on)		4042.5 (3463 - 4305)	655.0 (267.5, 821.0)	50958.0 (13511.5, 67786.0)	13551.5 (4929.5, 16729.5)		
Quarantine of close contacts based on history (past 2 days)	937.0 (929.0, 945.0)	10776.5 (9551.5 - 11564.5)	1530.5 (1441 - 1586)	930.5 (917.0, 939.5)	9445.5 (8541.5, 10191.5)	4673.5 (4549.5, 4780.5)		
Quarantine of all contacts based on history (past 2 days)	930.0 (917.0, 941.0)	11887.0 (11180.0 - 12831.5)	1614.5 (1550 - 1667)	919.0 (904.5, 931.5)	10662.0 (9718.0, 11768.5)	4842.5 (4741.0, 4957.0)		

Impact of community lockdown to augment initial public health response

In addition to the above measures, lockdown of non-quarantined households for 14 days in community is a highly effective strategy for epidemic control and reduces overall testing requirements by limiting the likelihood of successive waves of infection. In a community-wide lockdown, we assume that household members mix freely together (unlike quarantined household members) but do not associate with others in the community for 14 days.

The left panel of Figure 3 reproduces scenarios in the left panel of Figure 2 above, where extended household members are quarantined, with or without clearance testing. The right panel considers the addition of lockdown as an intervention, under alternative clearance testing scenarios. The synergistic impact of lockdown on epidemic control is clear, as undetected infections occurring in households outside those initially quarantined cannot seed other households over the 14-day period. It is, however, critical to ensure that new infections are not seeded when mixing resumes.

Figure 3: Impact of community lockdown. Epidemic curves for scenarios in which immediate and extended household members of the index case are quarantined and tested, without lockdown (left) or with lockdown (right), and under different levels of clearance test.



Table 3 demonstrates the marked impact of lockdown on epidemic control, building on the strategy of quarantining extended households, and comparing clearance testing from quarantine (only) with additional clearance testing from lockdown. Clearance testing from quarantine only may be effective, but there is a higher probability that cases may be reseeded into the community resulting in subsequent waves of infection, apparent from the shaded areas in the right panel of figure 3, and the broader range of cases, quarantine days and tests performed in the table below. Definitive control is more likely if clearance testing from lockdown is performed (bottom row).

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Table 3: Impact of lockdown - Effect on size of outbreak (total cumulative cases), quarantine person-days, and total tests performed during outbreak. Figures in the table are medians, with interquartile ranges.

Strategy		No lockdown	I	Full lockdown				
	Total Quarantine cumulative person- cases days (first year)		Total tests performed during outbreak (first year)	Total cumulative cases	Quarantine person- days (first year)	Total tests performed during outbreak (first year)		
Quarantine of extended (i.e. all) household contacts, with case isolation	831.5 (751.0, 871.0)	86825.0 (70334.5 - 97662.5)	4042.5 (3463 - 4305)	829.0 (712.0, 866.5)	85283.0 (69397.0, 92022.5)	3927.5 (3434.5, 4156.0)		
Quarantine of extended household contacts, AND clearance testing for contacts	655.0 50958.0 (267.5, (13511.5, 821.0) 67786.0)		13551.5 (4929.5, 16729.5)	88.5 (20.0, 432.5)	5253.5 (1660.5, 24531.0)	1402.0 (344.5, 7564.0)		
Quarantine of extended i.e. all household contacts AND clearance testing for everyone in lockdown	arantine of N/A N/A ended i.e. household tacts AND rrance ing for ryone in adown		N/A	35.0 (9.0, 62.5)	3469.0 (1431.5, 5602.5)	2498.0 (2169.5, 2823.5)		

Figure 4 demonstrates the importance of timely outbreak response for epidemic control, showing delays to intervention of 2, 4 or 6 days. In the right panel lockdown is implemented concurrent with case finding and quarantine, resulting in much improved epidemic control even where there are delays to implementation, compared with the 'no lockdown' case.

Figure 4: Impact of delay between test and response. Epidemic curves for a community of 1000 people where the initial outbreak response following identification of the index case is delayed by 2, 4 or 6 days. Contacts are quarantined according to the extended household definition, with entry and clearance testing. Epidemic outcomes are shown without lockdown (left) and with a perfectly applied lockdown at right.



Compliance with lockdown must be at least 80-90%

The effectiveness of lockdown as an intervention is highly contingent upon compliance with community mixing restrictions. 'Leaky' lockdowns will lead to a loss of epidemic control, with almost no benefit observed in communities of 1,000 or more people when compliance is less than 80%, as demonstrated in Figure 5, below.

Figure 5: Impact of compliance with lockdown. Epidemic curves for scenarios in which immediate and extended household members of the index case are quarantined and tested, with various levels of individual compliance with community lockdown. All individuals in isolation/quarantine/lockdown are subject to clearance testing. Multiple waves of reseeding and infection are observed if compliance is less than 80%, simulated at the level of the individual.



Impact of community size on model findings

The findings reported for a community of size 1,000 are generally applicable to the other population sizes investigated, with some caveats (Figure 6). The greatest benefits of lockdown are observed in a community of 3,500 people, where the larger population size provides greater potential for repeated cycles of infection as individuals are released from quarantine and normal community mixing resumes. As for a community of 1,000 however, this impact is contingent on a high degree of compliance with movement restrictions.

In small communities of 100-500 people, a large proportion of the population is likely to be interconnected through household membership. A contact definition based on households results in most of the community being quarantined, so the additional benefit of lockdown is more modest in a community of 500 and negligible in a very small community of 100. However, if social contacts over the preceding 48 hours are the basis of the contact definition, far fewer people are immediately quarantined, so lockdowns will have substantial benefit and more families can remain in contact with each other in the community rather than being quarantined separately elsewhere.

Figure 6: Impact of lockdown by community size, comparing 100, 500, 1,000 and 3,500 person communities. Epidemic curves shown are for scenarios in which immediate and extended household members of the index case are quarantined and tested, with or without lockdown achieved with 50% or 100% compliance. In smaller communities of size 100 or 500, immediate quarantine of closely interconnected households means that relatively few are left to 'lock down' resulting in no (community size 100) or modest (community size 500) benefits of this additional intervention. Clear benefits of well applied lockdowns are seen in larger communities where there is potential for multiple reseeding of infection after the initial outbreak response.



TECHNICAL APPENDIX

Model framework and assumptions

Population model

We use an individual-based model to explicitly represent each member of remote communities of different sizes, comprising 100, 500, 1,000 or 3,500 people, as representative of remote communities across northern Australian jurisdictions. This report focuses on communities of size 1,000 and notes key differences associated with population size. The model population comprises individuals aged 0-80 years, with the age, infection status and physical location of individuals tracked and updated daily. Individuals with the same home location are grouped into households. Contacts within households occur more frequently and infection is transmitted more easily. Each individual is recognised to have close family connections across a total of three households, between which their time is distributed as follows: main household (on/off) 9% of the time, second household (regular) 23% of the time, and third household (on/off) 9% of the time. Their remaining time (i.e. 2%) is spent at a randomly allocated household at the start of each times step. Contact (leading to transmission of infection) is also possible among individuals who are not in the same household (community contact) but in the same geographic location. Household distribution and contact rates are summarised in Table A1.

contacts for regional and remote communities								
Parameter	Value	Source						
Size of household (mean)	Regional = 4.5, Remote = 7.7	[1]						
Household distribution	Individuals stay at main household (core) 66% of the time, second household (regular) 23% of the time, third household (on/off) 9% of the time, and spend their remaining time (i.e. 2%) at a randomly allocated household	[2]						
Frequency of household contact per day.	Once per day	Assumption						

Table A1: Household size and contact rate. The two right-hand columns show the proportion of the population having the specified number of non-household contacts for regional and remote communities

household contact per day.	Once per day			Assumption
Frequency of		Regional (%)	Remote (%)	
non-household contact	1	20.7	25.0	
	1/7 to 1	54.5	50.6	[0]
	1/30 to 1/7	15.9	16.2	[3]
	1/90 to 1/30	5.2	4.2	
	0	3.7	4.1	

Disease model

The disease model follows a susceptible, exposed, infectious, recovered (SEIR) paradigm, allowing for infectiousness during both pre-symptomatic and symptomatic infection stages. An R_0 centring around 2.5 (1.4-5.7) was observed in initial phases of the COVID-19 pandemic in Wuhan, where the average household size is approximately 3. Assuming a similar per-contact transmission probability and noting the enhanced mixing associated with overcrowded households, R_0 in these simulations was calibrated to centre around 5 in the absence of any intervention. We assume that only half of all infections spontaneously present to health services, either because symptoms are absent or minimal, or because of fear and/or stigma. These non-presenting infections would not be routinely detected using a symptomatic case finding approach. Given the diverse reasons for non-presentation we conservatively assume that such individuals are as infectious as those with symptoms and may represent an ongoing infection risk following release from movement restrictions if undiagnosed.

The natural history of COVID-19 is assumed to follow the schematic diagram shown in Figure A1, and key natural history parameter assumptions in Table A2. Individuals susceptible to infection enter the latent stage after exposure before proceeding to the infected and infectious stage. Consistent with observations of pre-symptomatic transmission, for any given individual in the model, infectiousness may commence prior to or after symptom onset. A post-infectious stage is assumed prior to full recovery and individuals are assumed not to be infectious after symptoms resolve.

Model simulations commence with introduction of one infected individual at time=0, for each location evaluated.

Figure A1: Schematic diagram of stages and disease progression of COVID-19 in the model





Table A2: Parameters related to COVID-19 infection

Parameter	Distribution sample from	Source
Latent period (days)	Uniform distribution between 3 and 6	
Incubation period (days)	Weibull distribution of mean of 6.4 and SD of 2.3	[4-7] expert
Infectious period (days)	Weibull distribution of mean of 10 and SD of 4	opinions.
Post-infectious period (days)	Uniform distribution between 0 to 10	
Immunity following resolution of infection	Lifelong (i.e. no re-infection occurs post infectious period	Assumption
Transmission probability per contact	Uniform distribution between 0.15 and 0.20	Calibrated such that a R0 of 5.0 is maintain across the population. [8-10]1
Probability of symptomatic infection seeking treatment	99% seeking test within 8 days	Assumption
Probability of symptomatic infection	50%, 100%	Assumption

Response model

We assess the likely impact on the size of a local outbreak of a multi-layered public health response applied immediately following identification of the index case. In all instances, cases are assumed to be effectively isolated. We similarly assume the best case that quarantined individuals are completely protected from household and community transmission of infection, however that might be implemented in practice in a given setting.

¹ At the time of writing, COVID-19 is a new disease and estimation on R_0 is limited. Early study from Wuhan (where COVID-19 was first identified) suggested R_0 between 1.4 – 5.7. We have taken the upper end of this estimate as the typical household size in remote communities (7.7) is larger than those in China (3.03).



Different approaches to contact definition were compared (Figure 1), for consideration regarding feasibility of implementation within public health capacity.

We assess the impact of additional 14-day lockdown of all households in a community, concurrent with the first round of isolation and quarantine. Locked down households mix internally with other family members, but not with the community. We investigate the cases in which mixing of household members with others in the community varies between 50 and 100% compliance, implemented at the level of the individual rather than the household.

Laboratory testing

All quarantined individuals are tested at the time of entry into quarantine. Clearance testing is performed to confirm the absence of infection in isolated individuals at day 8, and quarantined individuals on day 12. These timings take into account the anticipated 2 days to receipt of the test result, enabling release into the community after the defined 10- and 14-day periods for isolation and quarantine, respectively. We further consider the benefits of testing all individuals prior to release from wider community lockdown. Identification of any new infection by testing initiates a new round of public health measures. If an individual in lockdown tests positive, their immediate household members would begin a 14-day cycle of quarantine, with assumptions as above.

Modelled delays between infection, testing and response measures

Figure A2: An example pathway for a typical individual with symptomatic infection. See accompanying text for explanation of the delays associated with each of the coloured arrows



The **onset of symptoms** is simply the incubation period of COVID-19 and is not affected by any intervention.

The **time between when onset of symptoms occurs and testing is sought** is dependent on the rate at which symptomatic individuals seek treatment, which 99% are assumed to do by the end of the 8 days infectious duration in the current model.

A quick note on asymptomatic infection: Asymptomatic do not actively seek testing, hence the time to testing will be determined by public health decisions about contact testing involving either household members or the general community.

The **time between diagnosis and availability of results** is governed by the test used (e.g. is it POC or does it need to be sent to a laboratory in another centre?). However, in the present model we assume responses are able to start immediately if the tested individual has symptoms.

The time between availability of results and the start of case isolation is assumed to be instantaneous in the current model.

Likewise, time between availability of results and commencement of contact tracing is also assumed to be instantaneous in the current model.

The time between the start of contact tracing and related response is currently set to zero but can be increased, should feedback indicated that this is necessary. Note for cycles of contact testing, it is assumed that the same delay to diagnosis and availability of results (the green arrow) will apply before initiation of related contact measures.

References

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Table A3: Characteristics of COVID-19 outbreaks in a community of population size 1000 under a range of scenarios regarding case isolation, quarantine and testing of contacts, delays between diagnosis and response, and lockdown.

#	Strategy	Outbreak duration (days)	Peak prevalence (%)	Final size of outbreak	Number of tests in first year of outbreak	Maximum number of tests in a single day	Number in isolation over first year of outbreak (person-days)	Maximum number in isolation in a single day	Number in quarantine over first year of outbreak (person-days)	Maximum number in quarantine in a single day
0	No response	56.0 (54.0, 58.0)	69.1 (68.0, 70.2)	999.0 (999.0, 999.0)	447.0 (435.5, 458.0)	42.0 (39.5, 45.0)	N/A	N/A	N/A	N/A
1	Isolation of index case only	57.5 (55.5, 60.0)	67.5 (66.3, 68.4)	999.0 (999.0, 999.0)	1221.0 (1188.5, 1250.0)	53.0 (51.0, 56.0)	7730.0 (7515.0, 7925.0)	380.0 (366.0, 388.0)	N/A	N/A
2	#1 + quarantine and test of index case's immediate households	141.0 (126.0, 155.0)	37.6 (31.9, 40.4)	922.0 (907.5, 936.5)	1957.5 (1867 - 2027)	121.0 (102 - 142)	3919.0 (3790.0 - 4173.0)	116.0 (109.5 - 120.0)	29595.5 (28101.5 - 31175.0)	797.5 (762.5 - 825.0)
3	#1 + quarantine and test of all index case's households	242.0 (155.0, 292.0)	13.7 (10.7, 16.5)	831.5 (751.0, 871.0)	4042.5 (3463 - 4305)	206.5 (159 - 257)	3027.5 (2332.0 - 3306.5)	31.5 (29.0 - 33.5)	86825.0 (70334.5 - 97662.5)	912.5 (867.0 - 936.0)

#	Strategy	Outbreak duration (days)	Peak prevalence (%)	Final size of outbreak	Number of tests in first year of outbreak	Maximum number of tests in a single day	Number in isolation over first year of outbreak (person-days)	Maximum number in isolation in a single day	Number in quarantine over first year of outbreak (person-days)	Maximum number in quarantine in a single day
4	#1 + quarantine and test of index case's close contacts from last 2 days	102.5 (92.5, 111.5)	45.7 (43.1, 48.1)	937.0 (929.0, 945.0)	1530.5 (1441 - 1586)	92.5 (83 - 105)	10981.5 (10805.5 - 11118.5)	522.0 (489.5 - 555.5)	10776.5 (9551.5 - 11564.5)	303.0 (289.0 - 316.5)
5	#1 + quarantine and test of all index case's contacts from last 2 days	109.0 (95.0, 120.5)	43.8 (40.9, 46.4)	930.0 (917.0, 941.0)	1614.5 (1550 - 1667)	94.0 (83 - 108)	11025.5 (10837.0 - 11238.0)	510.5 (469.0 - 544.0)	11887.0 (11180.0 - 12831.5)	322.0 (306.0 - 334.5)

					With clea	rance test				
6	#2 + clearance test	136.5 (126.5, 154.5)	36.5 (31.8, 40.7)	922.5 (905.0, 933.0)	7526.0 (7336 - 7743)	319.0 (268 - 371)	8689.5 (8392.5 - 8942.5)	294.0 (260.0 - 317.5)	22500.5 (21469.0 - 23306.0)	743.0 (683.0 - 771.5)
7	#3 + clearance test	115.5 (49.0, 238.0)	13.2 (10.6, 15.3)	655.0 (267.5, 821.0)	13551.5 (4929.5, 16729.5)	474.0 (395.5, 581.5)	6218.5 (2277.5, 7576.5)	110.5 (89.0, 126.5)	50958.0 (13511.5, 67786.0)	841.5 (752.0, 908.5)

#	Strategy	Outbreak duration (days)	Peak prevalence (%)	Final size of outbreak	Number of tests in first year of outbreak	Maximum number of tests in a single day	Number in isolation over first year of outbreak (person-days)	Maximum number in isolation in a single day	Number in quarantine over first year of outbreak (person-days)	Maximum number in quarantine in a single day
8	#4 + clearance test	102.0 (93.5, 115.0)	46.0 (42.8, 48.1)	930.5 (917.0, 939.5)	4673.5 (4549.5, 4780.5)	178.5 (168.5, 191.0)	14265.5 (14040.0, 14658.5)	570.0 (529.0, 597.0)	9445.5 (8541.5, 10191.5)	300.0 (282.0, 317.0)
9	#5 + clearance test	107.5 (92.5, 123.0)	43.3 (40.2, 46.1)	919.0 (904.5, 931.5)	4842.5 (4741.0, 4957.0)	181.0 (165.0, 199.0)	14373.5 (14080.0, 14587.5)	551.0 (518.5, 579.0)	10662.0 (9718.0, 11768.5)	317.5 (303.0, 339.0)
Wit	n lockdown									
10	#3 + full lockdown	238.0 (38.5, 278.3)	12.6 (9.7, 15.6)	829.0 (712.0, 866.5)	3927.5 (3434.5, 4156.0)	190.5 (139.0, 250.0)	2909.0 (2297.0, 3189.5)	31.0 (28.0, 33.0)	85283.0 (69397.0, 92022.5)	286.0 (112.0, 452.5)
11	#7 + full lockdown	41.0 (34.3, 72.5)	6.5 (1.6, 12.4)	88.5 (20.0, 432.5)	1402.0 (344.5, 7564.0)	198.0 (67.0, 432.0)	752.0 (197.0, 3703.0)	45.5 (11.5, 103.5)	5253.5 (1660.5, 24531.0)	384.0 (118.0, 776.0)
12	#11 + clearance test for lockdown	35.5 (29.5, 39.0)	3.1 (0.9, 5.2)	35.0 (9.0, 62.5)	2498.0 (2169.5, 2823.5)	1000.0 (1000.0, 1000.0)	420.5 (128.0, 735.5)	29.5 (8.0, 52.5)	3469.0 (1431.5, 5602.5)	286.0 (112.0, 452.5)

