1 # The lockdown of Hubei Province causing different transmission
2 # dynamics of the novel coronavirus (2019-nCoV) in Wuhan and
3 # Beijing

4 Xinhai Li[1,2]*, Xumao Zhao[3]*, Yuehua Sun[1,2]

5 [1] Key Laboratory of Animal Ecology and Conservation Biology, Institute of Zoology,
6 Chinese Academy of Sciences, Beijing, 100101, China
7 [2] University of Chinese Academy of Sciences, Yuquan Road, Beijing 100049, China
8 [3] State Key Laboratory of Grassland Agro-Ecosystem/Institute of Innovation Ecology,
9 Lanzhou University, Lanzhou, 730020, China

10 *The authors have the same contribution to the manuscript.

11 Correspondence to: sunyh@ioz.ac.cn; lixh@ioz.ac.cn

12 ## Abstract

13 **Background**

14 After the outbreak of novel coronavirus (2019-nCoV) starting in late 2019, a number
15 of researchers have reported the predicted the virus transmission dynamics. However,
16 under the strict control policy the novel coronavirus does not spread naturally outside
17 Hubei Province, and none of the prediction closes to the real situation.

18 **Methods and findings**

19 We used the traditional SEIR model, fully estimated the effect of control measures, to
20 predict the virus transmission in Wuhan, the capital city of Hubei Province, and
21 Beijing. We forecast that the outbreak of 2019-nCoV would reach its peak around
22 March 6 ± 10 in Wuhan and March 20 ± 16 in Beijing, respectively. The infectious
23 population in Beijing would be much less (only 0.3%) than those in Wuhan at the
24 peak of this transmission wave. The number of confirmed cases in cities inside Hubei
25 Province grow exponentially, whereas those in cities outside the province increase
26 linearly.

27 **Conclusions**

28 The unprecedented province lockdown substantially suspends the national and global
29 outbreak of 2019-nCoV.

30 **Key words:** city closure, quarantine, pandemic, public health, SEIR model,
31 transmission

1. Introduction

A novel coronavirus (2019-nCoV) appeared in December 2019 in Wuhan, Hubei Province in central China had triggered city closure on Jan. 23, 2020, and lockdown of all major cities in the province a few days later (Fig. 1). At present, over 50 million people are constrained locally. Due to the threat of 2019-nCoV to public health, World Health Organization (WHO) declared novel coronavirus (2019-nCoV) outbreak to be "public health emergency of international concern" on Jan. 30, 2020 [1]

It is always a great challenge to fight effectively against a pandemic [2, 3], especially when little is known about the new virus [4]. Ideally, governments, communities and medical services take rapid, effective, rational, and proportionate responses to such health emergencies; either minimalist or maximalist responses may potentially be very harmful [5, 6].

To facilitate decision making against the 2019-nCoV, researchers had predicted the transmission dynamics in different scenarios. Read et al. [7] estimated that only 5.1% (95% CI, 4.8–5.5) of infections in Wuhan were identified; ahead of 14 days, they predicted the number of infected people in Wuhan to be greater than 250 thousand on Feb. 4, 2020. Read et al. [7] suggested, before the city closure of Wuhan, that travel restrictions from and to Wuhan city are unlikely to be effective and 2019-nCoV would outbreak in Beijing, Shanghai, etc. with much larger sizes. Leung et al. [8] estimated the transmission dynamics of 2019-nCoV in six major cities in China under six scenarios: 0%, 25%, 50% transmission reduction with and without 50% mobility reduction. However, the assumption of 50% mobility reduction is much lower than the real situation. China government enforced tourism ban on Jan. 24, and carried out other control measures such as extending holidays, closing schools, cancelling meetings, suggesting a 14-day quarantine after travel. In particular, highway traffic control is strictly implemented in many cities, towns, and villages. The majority of communities in large cities such as Beijing and Shanghai have closed to visitors.

Under the circumstance of strict control measures, we forecast the transmission dynamics of Wuhan and Beijing. Wuhan is the source of 2019-nCoV, suffered a long history (two months) of virus transmission, with lack of medical resources to

2

63   quarantine exposed and suspect people. Beijing is a larger city with 22 million

64   residents, including 10 million inbound passengers after the holidays of Chinese New

65   Year. We believe our estimation is close to the real situation and is helpful for 2019-

66   nCoV control.
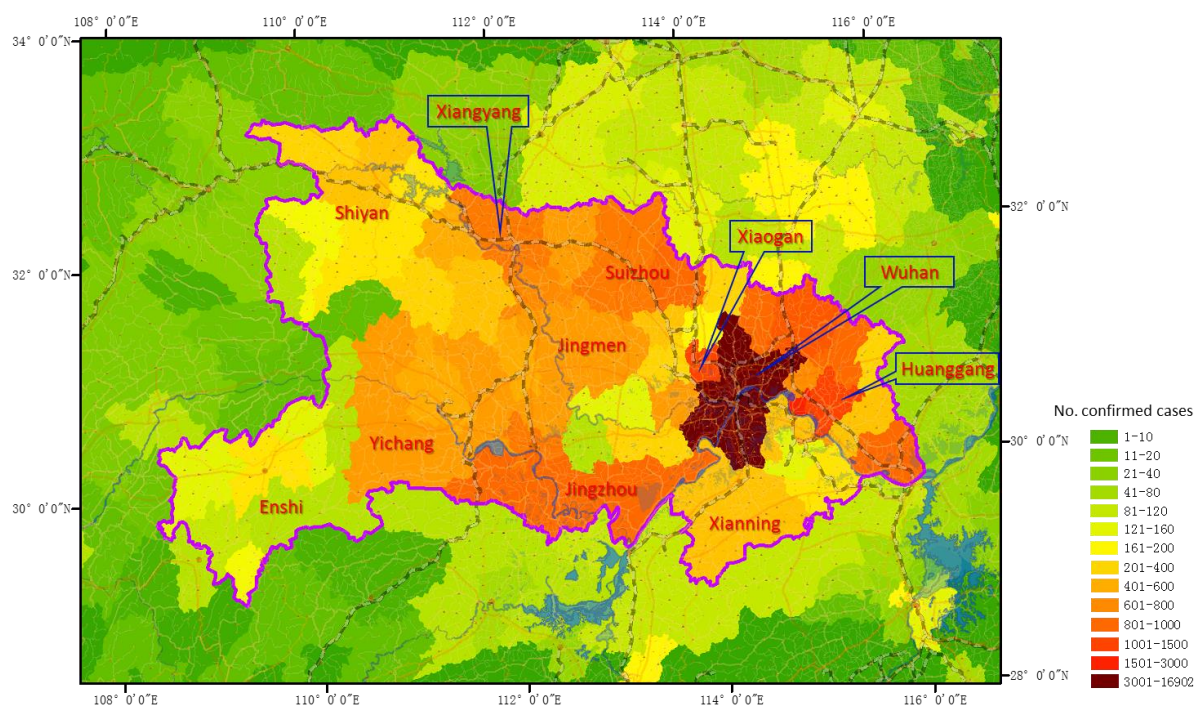
67   Fig. 1 Lockdown of Hubei Province to enclose novel coronavirus (2019-nCoV). The

68   gradient color represents the number of confirmed cases in Hubei Province and adjacent

69   areas on Feb. 9 (24:00), 2020.

70   **2. Methods**

71   We used the Susceptible-Exposed-Infectious-Recovered (SEIR) model to estimate the

72   dynamics of the novel coronavirus (2019-nCoV).

73   *2.1. The SEIR Model*

74   The SEIR model has the form [9]:

3

$$\frac{dS}{dt} = -\beta \frac{I}{N} S$$

$$\frac{dE}{dt} = \beta \frac{I}{N} S - \alpha E$$

(Equation 1)

$$\frac{dI}{dt} = \alpha E - \nu I$$

$$\frac{dR}{dt} = \nu I$$

75   where S is the susceptible population, E is the exposed population, I is the infectious

76   population, R is the recovered population, t is time (the number of days after the

77   emergence of the first case), N is the total population, β is the average number of

78   infected individuals per infectious subject per unit time, α is the reciprocal of average

79   latent period, ν is the rate of recovery (reciprocal of duration of the infection).

80   We assumed the infection rate of the novel coronavirus decreased when

81   temperature goes up starting from March 1, 2020, since other viruses have a seasonal

82   pattern (wave), such as the 2009 H1N1 pandemic [10]. As such, we defined the

83   decreasing infection rate exponentially as below:

$$\beta_t = \beta \times (1 - C)^{t-90} \text{ (Equation 2)}$$

84   where β_t is the infect rate at the time t (the first day, $t = 1$, is Dec. 1, 2019, based on

85   the first confirmation of 2019-nCoV on Dec. 8); C is a constant (simulated at 0.01-

86   0.1) defining the decreasing rate of transmission per day.

87   For the cities with continuous imported infected people, we modify the growth

88   rate of infectious population as:

89               $$dI/dt = \alpha E - \nu I + imported \text{ (Equation 3)}$$

90   where *imported* is the daily number of imported infections.

91   *2.2. Determination of Model Parameters*

92   The basic reproductive number R_0 for 2019-nCoV had been estimated in several

93   independent studies (Table 1). It was noticed that changes in reporting rate of

94   confirmed cases substantially affected R_0 estimation [11]. In fact, R_0 is highly

4

95   associated with the intensity of control measures. We used a series values of R_0 to fit

96   the number of cases in Wuhan and Beijing.

97   Table 1. The estimated basic reproductive number R_0 for 2019-nCoV

R_0	Lower CI	Upper CI	CV	Citations
3.8	3.6	4.0	0.05	[7]
2.68	2.47	2.86	0.07	[8]
2.24	1.96	2.55	0.13	[11]
3.58	2.89	4.39	0.20	[11]
2.90	2.32	3.63	0.22	[12]
2.92	2.28	3.67	0.23	[12]
6.47	5.71	7.23	0.12	[13]

98   The mean value of R_0 in Table 1 is 3.51, and the mean CV (coefficient of

99   variation) is 0.15.

100   The incubation period ($1/\alpha$ in SEIR model) was estimated as 6.4 (95% CI: 5.6 -

101   7.7) days, ranging from 2.1 to 11.1 days [14]. Liu et al. [12] provided a lower value,

102   4.8 days, for the period. Based on information from other coronavirus diseases, such

103   as SARS and MERS, the incubation period of 2019-nCoV could be up to 14 days

104   [15]. We used 6 days as the incubation period for our simulation.

105   Other model parameters are: population size of Beijing and Wuhan are 22

106   million and 10 million, respectively, based on the data (for 2018) provided by

107   National Bureau of Statistics of China at

108   http://data.stats.gov.cn/easyquery.htm?cn=E0105. The proportion of susceptible is

109   50% of the total population. The rate of recovery $v = 1/5$ per day. The basic

110   reproductive number R_0 does not directly used in the SEIR model. It has the following

111   function with the model variables and parameters: $R_0 = \beta/v \times S/N$.

112   To make our analysis repeatable, we posted the data used in this study and R

113   code for the SEIR model at https://github.com/Xinhai-Li/2019-nCoV.

114   **3. Results**

115   Until 9:00 on Feb. 9, the number of confirmed cases reaches 37251

116   (https://voice.baidu.com/act/newpneumonia/newpneumonia/?from=osari_pc_1). In

117   Hubei Province, the number of confirmed cases in the capital city Wuhan and other

118   prefecture-level cities grow exponentially; whereas in other cities in China, the

119   number of infections increase linearly (Fig. 2).
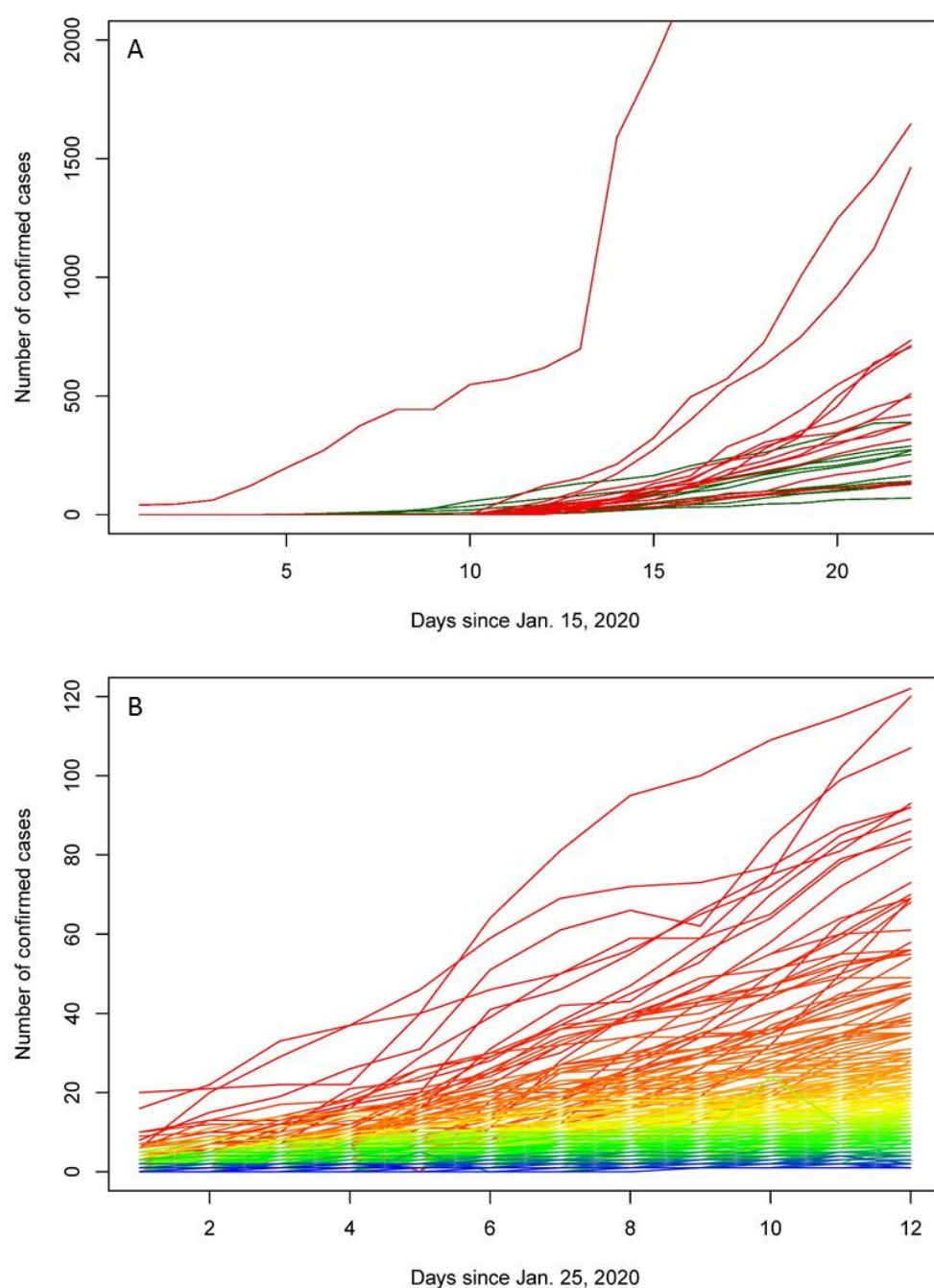
120   Fig. 2 The number of confirmed cases (Jan. 25 to Feb. 5) of 2019-nCoV in 332 cities in

121   China. A. The number of cases in top 26 cities. The red lines show the numbers of cases

122   in cities inside Hubei Province, and the green lines demonstrate those in other cities in

123   China. B. The number of cases in other 306 cities.

6

124   We simulated the virus transmission process using the SEIR model and
125 estimated the model parameters for Wuhan (Fig. 3) and Beijing (Fig. 4). For Wuhan,
126 we first fit the number of confirmed cases (Fig. 3A), where the R_0 is 5.75, much
127 higher than that in most studies yet lower than Tang et al.'s result (Table 1). Due to
128 the reality that a number of infected people in Hubei Province have not been checked
129 [7, 8], we fit a more realistic transmission dynamics, under a condition of a fixed
130 starting day on Dec. 1, 2019 (Fig. 3B). The best fit model having the R_0 5.0. After the
131 city closure on Jan. 23, the residents of Wuhan performed strong self-protection by
132 isolating themselves at home, so that we halved basic reproductive number to 2.5,
133 reflecting the pattern of family cluster infection of the virus. Since Feb. 8, a door-to-
134 door check was started in Wuhan in order to take all confirmed and suspected people
135 into medical care, and the transmission between family members dropped greatly. As
136 such, we further decrease the R_0 to 1.5. With these transmission rates, the infectious
137 population could reach the peak of $1.75 \pm 2.12 \times 10^5$ on March 6 ± 10, 2020. The

138 warming climate, based on Equation 2, may shorten the transmission duration by 1-2
139 months (Fig. 3D).

140   For Beijing, about half of the infections were directly imported from Wuhan [8].
141 We assume the infection flow would last for 30 days (from Jan. 19 to Feb. 18), caused
142 by the 10 million people leaving the returning Beijing for holidays. We simulated the
143 numbers of imported cases and found the best fit of daily imported cases for the 30
144 days following a normal distribution, with mean value and SD to be 19 ±12.7
145 individuals / day. To estimate the fluctuation of this time series of imported cases, we
146 calculated the standard deviation of the mean value (19 individuals / day) of the daily
147 imported patients from Jan. 19 to Feb. 8, which is 3.67. We adopted this uncertainty
148 to run 200 simulation, and found the R_0 1.4 is the perfect fit (Fig. 4A). Considering
149 the strict community locking (close to any visitors) and other extreme control
150 measures (such as office building control, i.e. checking body temperature for every
151 one and refusing visitors) in Beijing, we adopted a lower R_0 1.2 after the first 30 days
152 of transmission. The uncertainty of R_0 was simulated with CV = 15% (see Table 1),
153 and the results indicate that the infectious population may reach 607±553 on March
154 20 ± 16 (Fig. 4B). The uncertainty of the transmission dynamics, as simulated by the
155 SEIR model, is very high due to large variance in imported cases and R_0 (Fig. 4).
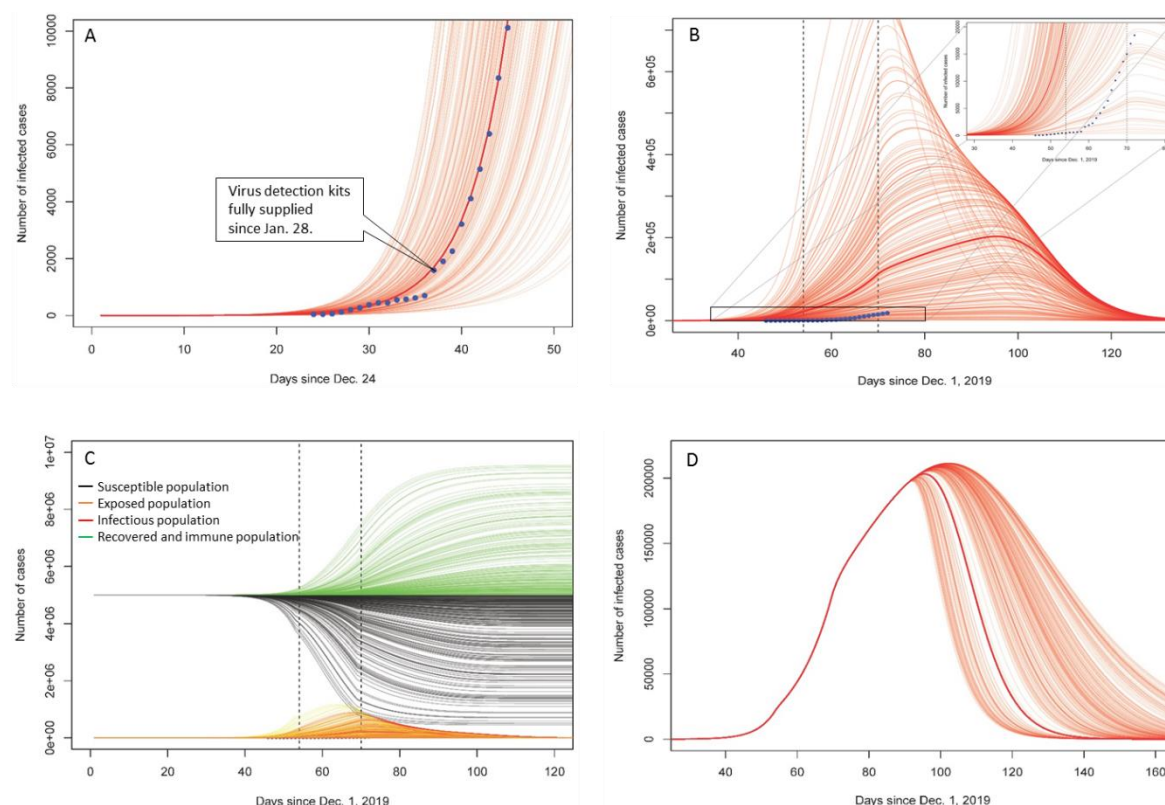
156 Fig. 3 Simulated (n = 200) 2019-nCoV transmission dynamics in Wuhan. The CV of R_0 is

157 15% for 200 simulations. A. Fit SEIR model to the published confirmed number of cases

158 in Wuhan. The blue dots show the number of confirmed cases. The R_0 is 5.75. B. Fit

159 SEIR model based on the "real" starting date on Dec. 1, 2019. The R_0 is 5 before Jan.

160 23, 2.5 between Jan. 23 and Feb. 8, 1.5 after Feb. 8. The dotted vertical lines indicate

161 the dates of city closure (Jan. 23) and door-to-door checking (Feb. 8). C. The dynamics

162 of susceptible, exposed, infectious and recover/immune populations. Fig. 3B is a part of

163 Fig. 3C. D. The dynamics of infectious population under the effect of warning climate (C =
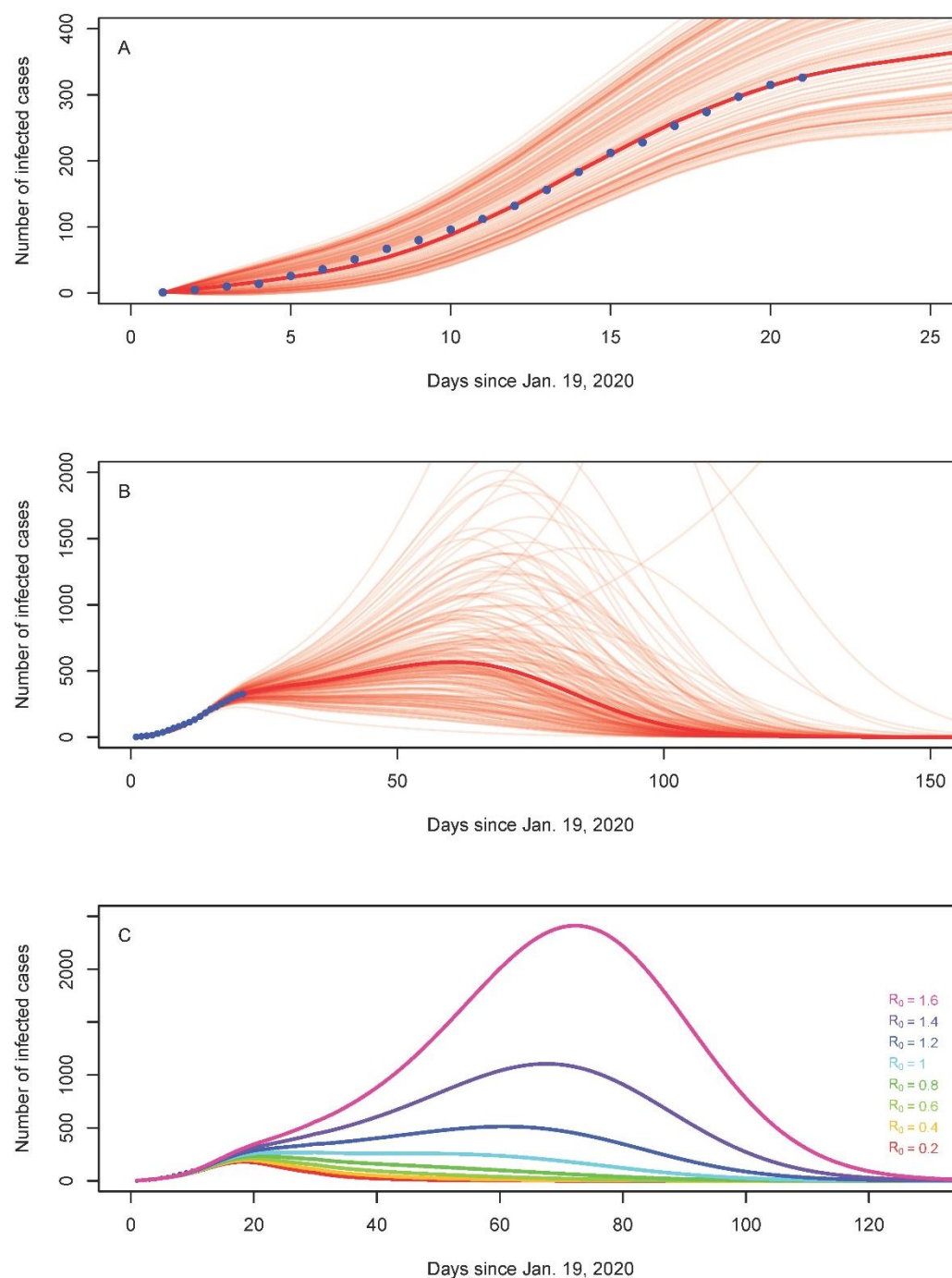
164 0.1, SD = 0.03).

Fig. 4 Predicted infectious population of 2019-nCoV in Beijing using SEIR. A. Predicted infectious population at the early stage of transmission. The mean imported cases of infection is 19 persons / day for 30 days, and the standard deviation of this mean value is 3.67 for 200 simulations. The R_0 is fixed at 1.4. The blue dots show the number of confirmed cases B. Predicted infectious population by 200 simulations at the whole transmission period. The R_0 decreases to 1.2 ± 0.18 due to strict control. C. Predicted infectious population in Beijing with a series of R_0 values. The parameter C (for temperature effect) in Equation 3 is 0.001 for Fig. 4B and Fig. 4C.

9

4. Discussion

We simulated the transmission dynamics of 2019-nCoV, with taking into account of the strict control measures enforced in the two cities. For Wuhan, city closure was a chock upon the local residents and they took much better protection than before. Accordingly, we halved the R_0 after the city closure. As to Beijing, strict control measures have been implemented. As a result, the local infection happened only 41 times until Feb. 3, with 124 people infected, which equals to half of the confirmed cases [16]. The dynamics of virus transmission are dramatically different within and without Hubei Province (Fig. 2), so that we gave different model parameters for the two cities. Our results about infectious population in Wuhan is lower than Read et al.'s estimation by 60%. Our estimation for Beijing is also much lower than the prediction of other studies [e.g. 7, 8]. We believe we provide a more realistic forecast, as we are witnessing the strict prevention activities carried out by all organizations and local communities in Beijing, and the linear increase (not exponential increase) of daily confirmed cases has proved the effectiveness of control measures.

China is running an antivirus campaign against 2019-nCoV. Besides the lockdown of Hubei Province, many cities blocked the highway and stopped the traffic through their domain. The longest vacation (for Chinese New Year) had been extended twice. The majority of people quarantine themselves at home for 14 days after travel. All domestic and international tourism were cancelled and banned. Numerous meetings, games, shows have been postponed. Schools are still closed. Compared with the prevention measures against SARS 17 years ago, this campaign has much stricter control on local communities (only accessible to residents). In the meantime, every people wear a musk during outdoor activities. Mandatory quarantine for close contactors is not enforced at this time.

There are three difficulties in the antivirus campaign. 1. The incubation period of 2019-nCoV is long. 2. Some patients have no symptoms yet they are infectious. Although a case of no symptom transmission [17] had been proved flaw [18], more other cases had been reported in many sources such as newspapers, website, and Wechat, etc. The current prevention method, body temperature checking, could not detect such people. 3. The false negative rate of 2019-nCoV diagnosis is high. For example, Dr. Wenliang Li (WHO Twitter mourned his death due to 2019-nCoV on

205 Feb. 6, 2020) had mentioned at his Wechat account that the nucleic acid detection for
206 him was negative, when he suffered breath difficulty. We think it would have a longer
207 fight (Fig. 3 & 4) against 2019-nCoV than SARS and MERS.

208   Wuhan can represent the situation of other cities in Hubei Province. After the
209 lockdown, these cities are isolated. Even over ten thousand medical workers from
210 other cities all over China have entered Wuhan for help, the infectious population is
211 still too large to be taken care of. However, starting from Feb. 2 and Feb. 8, two newly
212 established hospitals (Huoshenshan and Leishenshan Hospitals) with altogether 2500
213 beds for infectious patients have been already in service. With square bay hospitals
214 having been built and coming into use, and a door to door checking of all residents in
215 Wuhan started on Feb. 8, all infected and suspected people in Wuhan would be under
216 medical care. The infectious population in Wuhan, under the progressive prevention
217 activities, can be substantially lower (Fig. 3B) than the situation of natural
218 transmission of the virus.

219   Beijing is a representative of other large cities outside Hubei Province in China.
220 In Beijing, all confirmed and suspected cases have been taken into designated
221 hospitals, with their close contactors being tracked and quarantined in hotels or at
222 home. Similar controls are being implemented in other Chinese cities. The linear
223 increases of total number of confirmed cases (Fig. 2) indicates the spread of the virus
224 is under strictly control. The lockdown of Hubei Province substantially decreased the
225 imported infections, ensure the situation being manageable outside the province.

226   We kept the parameters of incubation period and serial interval constant for all
227 simulations. The uncertainty of these parameters also influences the results. The
228 estimation of R_0, its variance, and the rate of susceptible population, as well as the
229 effect of control measures and warming climate, are relatively arbitrary. In spite of the
230 weakness, we provide a more accurate estimation than previous studies. We hope our
231 results are valuable for instructing further antivirus activities.

232 **References**

233 1. Kupferschmidt K. Outbreak of virus from China declared global emergency.
234   Science. 2020. doi: doi:10.1126/science.abb1079.

11

235 2. Shetty P. Preparation for a pandemic: influenza A H1N1. Lancet Infect Dis.
236   2009;9(6):339-40. PubMed PMID: WOS:000266542300006.

237 3. Van Kerkhove MD, Asikainen T, Becker NG, Bjorge S, Desenclos JC, dos
238   Santos T, et al. Studies needed to address public health challenges of the 2009
239   H1N1 influenza pandemic: insights from modeling. Plos Medicine. 2010;7(6).
240   doi: 10.1371/journal.pmed.1000275. PubMed PMID: WOS:000279400000008.

241 4. Kamigaki T, Oshitani H. Influenza pandemic preparedness and severity
242   assessment of pandemic (H1N1) 2009 in South-east Asia. Public Health.
243   2010;124(1):5-9. doi: 10.1016/j.puhe.2009.11.003. PubMed PMID:
244   WOS:000274284400003.

245 5. Tarantola D, Amon J, Zwi A, Gruskin S, Gostin L. H1N1, public health security,
246   bioethics, and human rights. Lancet. 2009;373(9681):2107-8. PubMed PMID:
247   WOS:000267229700018.

248 6. Doyle A, Bonmarin I, Levy-Bruhl D, Le Strat Y, Desenclos JC. Influenza
249   pandemic preparedness in France: modelling the impact of interventions. J
250   Epidemiol Community Health. 2006;60(5):399-404. doi:
251   10.1136/j.jech.2005.034082. PubMed PMID: ISI:000236792400007.

252 7. Read JM, Bridgen JR, Cummings DA, Ho A, Jewell CP. Novel coronavirus
253   2019-nCoV: early estimation of epidemiological parameters and epidemic
254   predictions. medRxiv. 2020.

255 8. Leung K, Wu J, Leung G. Nowcasting and forecasting the Wuhan 2019-nCoV
256   outbreak. Preprint published by the School of Public Health of the University of
257   Hong Kong. 2020.

258 9. Hethcote HW. The mathematics of infectious diseases. Siam Review.
259   2000;42(4):599-653. PubMed PMID: WOS:000165673600003.

260 10. Fang L-Q, Wang L-P, de Vlas SJ, Liang S, Tong S-L, Li Y-L, et al. Distribution
261   and risk factors of 2009 pandemic influenza A (H1N1) in mainland china. Am J
262   Epidemiol. 2012;175(9):890-7. doi: 10.1093/aje/kwr411. PubMed PMID:
263   WOS:000303653000006.

264 11. Zhao S, Lin Q, Ran J, Musa SS, Yang G, Wang W, et al. Preliminary estimation
265   of the basic reproduction number of novel coronavirus (2019-nCoV) in China,
266   from 2019 to 2020: A data-driven analysis in the early phase of the outbreak.
267   International Journal of Infectious Diseases. 2020. doi:
268   https://doi.org/10.1016/j.ijid.2020.01.050.

269 12. Liu T, Hu J, Kang M, Lin L, Zhong H, Xiao J, et al. Transmission dynamics of
270   2019 novel coronavirus (2019-nCoV). bioRxiv. 2020.

271 13. Tang B, Wang X, Li Q, Bragazzi NL, Tang S, Xiao Y, et al. Estimation of the
272   transmission risk of 2019-ncov and its implication for public health interventions.
273   Available at SSRN 3525558. 2020.

274 14. Backer JA, Klinkenberg D, Wallinga J. The incubation period of 2019-nCoV
275   infections among travellers from Wuhan, China. medRxiv. 2020.

276 15. WHO. Q&A on coronaviruses: How long is the incubation period? 2020 [2020-2-
277   5]. Available from: https://www.who.int/news-room/q-a-detail/q-a-coronaviruses.
278 16. He X. The local infection of novel coronavirus in Beijing Beijing Business
279   Newspaper. 2020 Feb. 3, 2020.
280 17. Rothe C, Schunk M, Sothmann P, Bretzel G, Froeschl G, Wallrauch C, et al.
281   Transmission of 2019-nCoV Infection from an Asymptomatic Contact in
282   Germany. New Engl J Med. 2020.
283 18. Kupferschmidt K. Study claiming new coronavirus can be transmitted by people
284   without symptoms was flawed. Science. 2020. doi: doi:10.1126/science.abb1524.