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Implications of the COVID-19 lockdown on dengue transmission and the occurrence of  
*Aedes aegypti* (Linnaeus) and *Aedes albopictus* (Skuse) in Malaysia

Song-Quan Ong<sup>1,2</sup>, Hamdan Ahmad<sup>2</sup>, Ahmad Mohiddin Mohd Ngesom<sup>3,4</sup>

<sup>1</sup>UOW Malaysia KDU Penang University College, 32, Jalan Anson, George Town, George  
Town, Pulau Pinang

<sup>2</sup>Vector Control Research Unit, School of Biological Sciences, Universiti Sains Malaysia,  
Penang, Malaysia

<sup>3</sup>Faculty of Health Science, Universiti Kebangsaan Malaysia, Jalan Raja Muda Abdul Aziz,  
Kuala Lumpur

<sup>4</sup>Penang State Health Department, Tingkat 35 & 37, Komtar, Penang, Malaysia

\*Corresponding author

E-mail: [songguan26@gmail.com](mailto:songguan26@gmail.com)

## 37 **Abstract**

38           The impact of movement restrictions (MRs) during the COVID-19 lockdown on the  
39 existing endemic infectious disease dengue fever has generated considerable research interest.  
40 We compared the curve of weekly epidemiological records of dengue incidences during the  
41 period of lockdown to the trend of previous years (2015 to 2019) and a simulation at the  
42 corresponding period that expected no MRs and found that the dengue incidence declined  
43 significantly with a greater magnitude at phase 1 of lockdown, with a negative gradient of 3.2-  
44 fold steeper than the trend observed in previous years, indicating that the control of population  
45 movement did reduce dengue transmission. However, starting from phase 2 of lockdown, the  
46 dengue incidences demonstrated an elevation and earlier rebound by 4 weeks and grew with  
47 an exponential pattern. Together with our data on *Aedes* mosquitoes, we proposed a stronger  
48 diffusive effect of vector dispersal that led to a higher rate of transmission. From the result of  
49 the *Aedes* survey using human landing caught (HLC), we revealed that *Aedes albopictus* is the  
50 predominant species for both indoor and outdoor environments, with the abundance increasing  
51 steadily during the period of lockdown. We only recovered *Aedes aegypti* from the indoor  
52 environment, which is relatively fewer than *Ae. albopictus*, by contrasting their population  
53 growth, which suggested that *Ae. albopictus* invaded and colonized the habitat of *Ae. aegypti*  
54 during the period of lockdown. These findings would help authorities review the direction and  
55 efforts of the vector control strategy.

56

## 57 **Author summary**

58           COVID-19 pandemic is taking hold globally and dengue fever transmission is not on  
59 the top of the list of concerns. With a partial lockdown implemented by Malaysia on 18 March,  
60 we postulate the movement restrictions (MRs) of people in large-scale would hamper the  
61 regular dengue transmission and aim to reveal the impact of MRs on both dengue incidences  
62 and *Aedes* mosquitoes. We showed a significant decline of dengue incidences at the beginning  
63 of lockdown but later rebounded at an earlier time and higher rate compared to the  
64 corresponding period of previous years. Our result also reviews how adaptive the *Ae.*  
65 *albopictus* with the movement of the host, as the human contained in the house, the abundance  
66 of the mosquitoes increased significantly during the period of lockdown. We also suggest that  
67 *Ae. albopictus* could be the key substitution vector that contributes significantly to dengue virus  
68 circulation, and therefore, the vector control direction and strategies should be redesigned.

## 69 **Introduction**

70 Lockdown has been commonly implemented all over the world to halt COVID-19 transmission  
71 [1]. This is to control human movement, as physical proximity is a key risk factor for the  
72 transmission of SAR-CoV-2 [2]. Although the physical proximity of humans shapes the spatial  
73 spread of a pathogen, it refers mostly to directly transmitted infectious diseases [3] such as  
74 COVID-19, but the effect on indirectly transmitted infectious diseases such as dengue fever  
75 (DF) remains unclear. By using an agent-based transmission model, Reiner et al. [4] indicated  
76 that the socially structured movement of humans caused a significant influence on dengue  
77 transmission, although the infection dynamics were hidden by the diffusive effect of  
78 mosquitoes. Falcón-Lezama et al. [5] used a mathematical model to evaluate the effect of  
79 people's day-to-day movement on the dengue epidemic and concluded that the vector-host and  
80 spatial connectivity posted epidemic risk. To simulate the actual situation, Stoddard et al. [6]  
81 used contact-site cluster investigations in a case-control design to review the risk of dengue  
82 infection by human movement and argued the importance of movement restriction in managing  
83 the spatiotemporal dynamics of dengue virus. However, the previous experimental  
84 configurations were far from the real situation, especially when the mobility of the population  
85 on a large scale is not feasible to demonstrate the direct effect on dengue transmission.

86         Dengue fever (DF) is the most prevalent mosquito-borne disease in the world [7]. For  
87 the past two decades, DF has been the central public health problem for Malaysia, and the  
88 endemic dengue in Malaysia is seasonal, with variable transmission and prevalence patterns  
89 affected by the large diversity in rainfall and spatial variation [8]. The major transmission  
90 periods of DF occur from June to September, following the main rainy seasons. The minor  
91 transmission period is from September to March, following monsoon rains sessions that bring  
92 higher precipitation and lead to the greater potential breeding ground for the vector [9]. Since  
93 the end of the minor peak and the start of major peaks of DF transmission often coincides with  
94 the duration of the COVID-19 lockdown, we are particularly interested in the impact of  
95 movement restrictions on the endemic of dengue transmission and vector occurrence. With the  
96 imposition of the COVID-19 partial lockdown in Malaysia, about 90% of people were  
97 restricted to their homes, and 10% essential workers were allowed to carry out their daily  
98 activities [10]; thus, the unprecedented large-scale movement restriction highly potentially  
99 spurred dengue endemics.

100 The spatial distribution of the DF vectors *Aedes aegypti* and *Aedes albopictus* are  
101 potentially affected by movement restrictions (MRs). Both *Ae. aegypti* and *Ae. albopictus* are  
102 highly anthropophilic, in which *Ae. aegypti* almost exclusively rely on human blood and *Ae.*  
103 *albopictus* is an aggressive and highly adaptive species that can easily colonize the habitat of  
104 other mosquitoes in urban areas [11]. Numerous studies [11-13] have shown that the  
105 occurrence of *Aedes* mosquitoes is significantly different from the human population density,  
106 strongly supporting the idea that vector-parasite interactions depend on the spatial distribution  
107 of the host. In addition, the spatial distribution of the host also influenced the behavior of the  
108 vectors, and previous studies [14-15] identified a shift of the *Ae. albopictus* habitat to an indoor  
109 environment where the species usually inhabit the forest or are mostly vegetative and cause  
110 interspecies competition with other existing mosquito species, such as *Ae. aegypti*. Therefore,  
111 when the COVID-19 partial lockdown restricts humans in mostly indoor environments with  
112 minimum outdoor activities, the occurrence of mosquitoes is desirable.

113 We study the effect of the physical proximity restriction on humans during the COVID-  
114 19 lockdown in Malaysia on two main variables:

115 **Dengue transmission trend.** One of the goals in this study is to understand the impact of MRs  
116 on the trend of dengue transmission. We conduct a temporal analysis for dengue incidences  
117 from 2015 to 2019 and construct a simulation that expects no MR practice and statistically  
118 compares the actual trend with the trends of previous years and simulation to evaluate the level  
119 of heterogeneity.

120 **The occurrence of vectors.** We do not know the extent to which movement restriction  
121 influences vector dynamics and therefore aim to obtain data on the abundance and distribution  
122 of *Aedes* mosquitoes during a period of lockdown by conducting sampling in the indoor and  
123 outdoor environments of an area that was historically a dengue hotspot.

124

## 125 **Methods**

### 126 **Data collection**

127 We started the analysis from the data of 2015, which recorded the second-highest dengue  
128 incidence after 2019 [16]. We retrieved the data from the official press statement and the  
129 Dengue Surveillance System developed by the Vector-Borne Disease Section, Ministry of  
130 Health (MOH), Malaysia, to monitor dengue transmission using remote sensing (RS) –

131 iDengue [17], under the supervision of Remote Sensing Agency Malaysia. This surveillance  
132 system monitors dengue transmission across the country by updating dengue fevers reported  
133 in every hospital and medical institution on a daily basis, and all notified cases were followed  
134 up by the relevant health authorities for case verification before being recorded in the registry  
135 of the Dengue Surveillance System.

136

### 137 **Temporal analysis of dengue incidences during partial lockdown**

138 We observed the previous temporal pattern of dengue incidences and found that the period of  
139 the COVID-19 partial lockdown (March 18 to June 9, 2020) coincided between the end of  
140 minor (March-May) and the start of major (June-Sept) fluctuations of dengue transmission (Fig.  
141 1). Therefore, to understand the heterogeneity of the trend of weekly incidences due to the  
142 partial lockdown, we compared the trend with two reference trends, namely, simulation and  
143 mean weekly incidence from 2015-2019. Both references were without the interference of city  
144 lockdown and population movement control. To construct a simulation, we applied auto-  
145 regressive integrated moving average (ARIMA) models, which are advantageous for modeling  
146 the time-based dependent configuration of a time series [18] and are commonly applied for  
147 epidemiological surveillance. We trained the models by using weekly dengue incidences from  
148 the dataset from 2015 to 2019 and the means of the incidences. To select the best-fitting dataset  
149 to construct the weekly trend of dengue incidence during the COVID-19 partial lockdown of  
150 Malaysia, the simulated model before lockdown (weeks 1 to 12 of 2020) was correlated with  
151 the actual weekly trend of dengue incidences by using Spearman rank correlation at the  
152 significance level of 0.05 (SPSS 17.0, IBM Corp. IBM SPSS Statistics for Windows, Version  
153 17.0. Armonk, NY: IBM Corp.), and the dataset with the strongest correlation was selected to  
154 further develop the simulated trend during the partial lockdown. To refine the ARIMA model,  
155 we finetuned the parameter (p,d,q) [p is the order of autoregression, d is the degree of  
156 differencing, q is the order of the moving-average model] based on the model proposed by  
157 previous studies [19-20]. The best-fitting model was selected based on the lowest values of the  
158 normalized Bayesian information criterion (NBIC) and the root mean square error (RMSE)  
159 [20]. Furthermore, we divided the time series of weeks 1 to 24 of 2015-2020 into eight stages  
160 (two prelockdown periods, five phases during the partial lockdown, and postlockdown)  
161 according to the announcement from the Malaysia government [21] (Fig. 1 and Table 1) and  
162 compared the actual weekly dengue incidences during the period of partial lockdown with the

163 those of the simulation and previous years (2015-2019) using two-way ANOVA with two  
164 independent variables, namely, years and stages. Because the trends follow an open-up  
165 parabolic pattern, we further distinguish the pattern by comparing the slopes for the stages to  
166 study the rates of decline and endemic incline.

167

168 **Fig 1. Dengue endemic growth from years 2015 to June of 2020.** Eight stages: Pre2, Pre-  
169 lockdown 2; Pre1, Pre-lockdown 1; P1, Phase 1; P2, Phase 2; P3, Phase 3; P4, Phase 4; P5,  
170 Phase 5; Post, Post-lockdown

171

172 Table 1 Division of Eight Stages of time series for data analysis

Stages	Phases	Terms	Time
1	Pre-2		19 February to 3 March
2	Pre-1		4 March to 17 March
3	P1*	MCO	18 March to 31 March
4	P2	MCO	1 April to 14 April
5	P3	MCO	14 April to 28 April
6	P4	MCO	29 April to 12 May
7	P5	CMCO	13 May to 9 June
8	Post	RMCO	10 June to 31 August

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MCO - Movement Control Order

CMCO - Conditional Movement Control Order

RMCO - Recover Movement Control Order

\*for 2020, week 12 remarks the starting of COVID-19 partial lockdown

## 178 Mosquito abundance and distribution

179 **Site selection.** To understand dengue transmission, we have to assess the abundance and  
180 distribution of *Aedes* mosquitoes during the host MR, and we are particularly interested in the  
181 spatial distribution of the vector for indoor and outdoor environments due to the possibility of  
182 a decrease in artificial breeding sites reported at the beginning of lockdown [22] and the host  
183 contained in their housing area. The sites were selected from a residential area, namely, Taman  
184 Bukit Jambul, Bayan Lepas, Penang Island, Malaysia (GPS - 5°20'06.6"N 100°17'18.7"E),  
185 which is located within the Southwest Penang Island District and was a dengue hotspot area in  
186 2005 and 2017 [23]. Due to the restriction of movement, the sampling was conducted within a  
187 10-km radius from the home of the participant [24]. The sampling was assessed at five outdoor  
188 (n=5) and indoor (n=5) locations covering an area of 12.11 hectares (Fig. 2).

189

190 **Fig. 2 Sampling locations at Taman Bukit Jambul, Penang Malaysia**

191

192 **Human landing catch (HLC).** For high anthropophilic mosquitoes, the human landing catch  
193 (HLC) method is the most effective sampling method [25], although it poses the risks of the  
194 human contracting the mosquito-borne pathogen, especially at the location where dengue and  
195 chikungunya are endemic. We obtained consent from the participant for the first author (male,  
196 blood group A+, 33 years old, BMI 24.22 kg/m<sup>2</sup>), who is a trained medical entomologist, to  
197 conduct the sampling at the location. The caught was performed in the early morning from 7:30  
198 A.M. to 10 A.M. with the left arm and both legs exposed without any artificial chemical (e.g.,  
199 lotion and body shampoo) interference; the mosquitoes were collected by a manual aspirator  
200 and transferred to a sealed container. Mosquitoes were killed by freezing, counted, and  
201 identified using taxonomy keys. The counts of *Ae. aegypti* and *Ae. albopictus* from indoor and  
202 outdoor locations for the eight stages of the time series during partial lockdown were compared  
203 by using two-way ANOVA with post hoc LSD.

204 **Mosquitoes taxonomy.** We focused on two main vectors of dengue in Malaysia – *Ae. aegypti*  
205 and *Ae. albopictus* in which contribute to the majority of dengue incidences [26]. The  
206 identification of mosquitoes was assisted with a device – *Aedes* Detector that able to enlarge  
207 the specimen with high resolution. In addition to the common distinguish features - the lyre-  
208 shaped markings on *Ae. aegypti* and the white stripe marking on the thorax of *Ae. albopictus*,  
209 we also focused on the scutellum and clypeus-pedicel parts of the mosquitoes that consisted of  
210 distinctive white scales on the mesepimeron on *Ae. aegypti*.

211

212 **Results**

213 **Temporal analysis of dengue incidences during partial lockdown**

214 Most of the studies on the growth of dengue incidences in Malaysia have focused on the total  
215 cases reported annually, in which the proposed model may not be sensitive and flexible enough  
216 to predict growth and propose necessary management. To our knowledge, this study is the first  
217 to report a simulation model with weekly dengue incidences in 2020, including the period of  
218 COVID-19 partial lockdown in Malaysia. To select the best-fitting simulation model, Table 2  
219 shows the comparison of the NBIC, RMSE, and MAPE of three ARIMA models, and the best-  
220 fitting forecast model for dengue incidences is ARIMA (1,1,0) due having the lowest NBIC

221 and RMSE. The dataset of the mean weekly incidences of dengue incidences from 2015 to  
222 2019 was selected to conduct the simulation because the strongest correlation ( $r = 0.909$ ,  
223  $p < 0.001$ ) was obtained for weeks 1 to 12 of 2020 (before partial lockdown) with the actual  
224 incidences trend. As seen in Fig. 3, when we generated a simulated model on the trend of weeks  
225 12 to 24 of 2020, which coincided with the COVID-19 partial lockdown period in Malaysia,  
226 the actual dengue incidence trend was significantly diverted and demonstrated a strong  
227 negative correlation compared with the simulated trend ( $r = -0.944$ ,  $p < 0.001$ ), which implied  
228 that the actual dengue incidence trend significantly disobeyed the simulation, which presumed  
229 no lockdown, indicating that movement control greatly impacted dengue transmission in  
230 Malaysia.

231

232 Table 2 ARIMA model evaluation

Model	(0,1,0)	(1,1,0)	(1,1,1)
NBIC	9.44	9.38	9.46
RMSE	107.80	100.97	101.07
MAPE	4.11	3.77	3.73
$R^2$	0.89	0.91	0.91

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NBIC = Normalized Bayesian Information Criterion  
RMSE = Root Mean Square Error  
MAPE = Mean Absolute Percentage Error

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239 **Fig. 3 Simulation of dengue incidence by using mean of 2015 to 2019 weekly incidences**  
240 **and correlation between the simulated and the actual trend before and the duration of**  
241 **partial lockdown.** ULC, upper confidence level; LCL, lower confidence level.

242

243 To further analyze the changes in dengue incidence trends due to the partial lockdown,  
244 we divided the time series of endemical weeks into eight stages as described in Table 1, and  
245 Fig. 4 describes the comparison of the eight stages for previous years (mean weekly incidence  
246 of 2015-2019), the simulated trends and actual dengue incidences during the COVID-19 partial  
247 lockdown, and the slope for the particular stages. Although many researchers have indicated  
248 that the dengue incidences in 2020 were lower than those in 2019 [16], when we averaged the  
249 weekly incidences of the previous five years (2015-2019), 2020 had significantly higher  
250 dengue incidences at prelockdown 1 and 2. Nevertheless, the slopes between the dengue

251 incidences of the previous years and those of the year 2020 during the period of prelockdown  
252 (1 and 2) are fairly the same. When Malaysia imposed phase 1 of the partial lockdown, the  
253 slope declined dramatically, which was 319% steeper than in previous years. This provides a  
254 strong implication that movement control during partial lockdown significantly reduced the  
255 reported dengue incidences. Although at phases 2 to 4, the incidences in 2020 were  
256 significantly lower than those in previous years, when we compared the stages for the slope to  
257 become positive (which indicates an upsurge in dengue incidences), this change in slope  
258 occurred in 2020 two stages (4 weeks) earlier than in previous years; specifically, a positive  
259 slope was obtained at phase 3 in 2020 compared to in previous years, in which a positive was  
260 obtained at phase 5. Furthermore, at phase 5, the steepness of the slope of the year 2020 spiked  
261 from phase 4 to postlockdown compared to previous years, with the steepness increasing from  
262 22% to 227%, suggesting a significant increase in dengue transmission.

263

264 **Fig. 4 Analysis of variance (ANOVA) of dengue incidences of mean, simulation and year**  
265 **2020 for eight stages of COVID-19 partial lockdown in Malaysia and the slope for the**  
266 **stages.** Pre-LD-2, Pre-lockdown-2; Pre-LD-1, Pre-lockdown-1; P1, Phase 1; P2, Phase 2; P3,  
267 Phase 3; P4, Phase 4; P5, Phase 5; Post-LD, post-lockdown.

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## 270 **Distribution of mosquitoes**

271 To study one of the factors that contributes to the spread-out of dengue transmission during the  
272 COVID-19 partial lockdown, we assessed the abundance and distribution of vectors during the  
273 partial breakdown. Fig. 5 shows the temporal numbers of *Ae. albopictus* collected from the  
274 outdoor area of the sampling location during the period of partial lockdown. *Ae. albopictus* is  
275 the predominant species in the outdoor area, with no *Ae. aegypti* was caught. The abundance  
276 of *Ae. albopictus* showed slight fluctuation patterns during the partial lockdown but still  
277 demonstrated a strong linear increment ( $R^2 = 0.7199$ ) throughout the eight stages of partial  
278 lockdown. In general, the total number of mosquitoes caught indoors was significantly lower  
279 than that outdoors, and we reported the occurrence and abundance of *Aedes* mosquitoes in the  
280 indoor environment during COVID-19 and found that both *Ae. aegypti* and *Ae. albopictus* were  
281 caught indoors, with the abundance of *Ae. aegypti* being relatively low and plateauing

282 throughout phase 3 to post-LD. However, *Ae. albopictus* demonstrated higher abundance and  
283 exponential growth with the population during the same corresponding period (Table 3).

284

285 Table 3 Total *Aedes* mosquitoes caught from indoor environment of sampling location

Phases	<i>Aedes aegypti</i>	<i>Aedes albopictus</i>
P3	0	4
P4	3	2
P5	4	9
Post	2	12

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P3, Phase 3

P4, Phase 4

P5, Phase 5

Post, post-lockdown

291 Our objectives did not include the correlation between dengue incidences and  
292 mosquito's abundances. This is due to these few reasons – (1) The extent of dengue  
293 transmission is determined by multiple factors, exp. the level of herd immunity in the  
294 population, the virulence of virus, survival, feeding behavior of vectors, etc.; (2) Non-aligned  
295 of sampling timeline and location between the dengue incidences and entomological data, the  
296 participant started the outdoor sampling on 22 March (phase 1 of lockdown), and therefore no  
297 data for the pre-lockdown is available. Furthermore, due to the rules of movement restriction,  
298 indoor sampling could only happen at the lobby (ground floor)

299

300 **Fig. 5 Total counts of *Aedes albopictus* for the dates and phases of COVID-19 partial**  
301 **lockdown at the outdoor environment of sampling location.**

302

303

## 304 Discussion

305 The factors that contribute to dengue transmission are multifaceted, and the spatial variation in  
306 the contact rates of the host and vector are probably the most important factors for the dynamics  
307 of DENV [27]. With the MRs imposed due to the COVID-19 pandemic, we can investigate the  
308 effect of the large-scale MRs of the host on two interrelated variables: dengue transmission and  
309 spatial distribution of *Aedes* mosquitoes. We analyze the dengue incidence trends by comparing  
310 their significant differences among the stages before, during, and after the lockdown to those

311 of the same corresponding periods for previous years and simulation. We first reported  
312 evidence that the MRs of the COVID-19 partial lockdown significantly influenced the weekly  
313 dengue incidence trend in Malaysia. Our findings provide direct evidence from analysis and  
314 extend the studies of Reiner et al. [4] and Falcón-Lezama et al. [5], which demonstrated that  
315 people's movement affected dengue transmission by using a simulation model. The early  
316 decline in dengue incidences was also reported in India, with dengue cases dropping by 50%  
317 compared to previous years. The decline of incidences at the beginning of the lockdown could  
318 have occurred for several reasons: (1) fewer hosts available outdoors and therefore less vector-  
319 host contact, as *Ae. aegypti* and *Ae. albopictus* are exophilic [28]; (2) the alteration of the  
320 environment and relatively fewer artificial breeding sites for the vector due to less solid waste  
321 from humans [22]; and (3) the limited movement of infected patients due to the COVID-19  
322 partial lockdown.

323 Unfortunately, our analysis showed that the dengue incidences rebounded earlier and  
324 spiked up at a higher rate than in previous years, indicating that the large-scale MRs of the  
325 population are not sustainable in controlling the spread of dengue. The finding is compatible  
326 with the situation in Singapore, which has had the most serious dengue outbreak in seven years  
327 [29], and an agent-based simulation model study by Jindal and Rao [30] that showed a  
328 significantly higher risk and severity of dengue transmission after the COVID-19 partial  
329 lockdown. The stay-at-home situation makes the host available most of the time in the indoor  
330 environment and optimizes the biting activities for endophagic *Ae. aegypti* to transmit the virus.  
331 In contrast to Harrington et al. [31], who argued that people, rather than mosquitoes, rapidly  
332 move the virus within and between rural communities and places due to the limitation of the  
333 flight range of female *Ae. aegypti*, our result of *Aedes* mosquitoes revealed that the element of  
334 vector dispersal plays a more crucial role in spreading the virus. We also proposed the idea of  
335 the vector *Ae. Albopictus*, which showed increased abundance during the MRs on people posted  
336 to a stronger diffusive effect of vector dispersal and therefore caused earlier rebound and a  
337 higher rate of dengue transmission during lockdown. We also suggest that *Ae. albopictus* could  
338 be the key substitution vector that contributes significantly to dengue virus circulation, and  
339 therefore, the vector control direction and strategies should be redesigned.

340 With no current entomological data about female adult *Ae. albopictus* in the  
341 corresponding period with lockdown, we refer to Rozilawati et al. [12] and Rahim et al. [32],  
342 who studied the seasonal abundance of *Ae. albopictus* in Penang by sampling eggs, the Ovitrap  
343 index, the container index (CI), the house index (HI) and the Breteau Index (BI). Their results

344 demonstrated that the indexes of *Ae. albopictus* for the corresponding period of phase 2 to 4 of  
345 lockdown should be lower, in contrast to our finding that the abundance of *Ae. albopictus*  
346 increased steadily from phases 1 to 5. There are several reasons for the increase in *Ae.*  
347 *Albopictus*. First, as proposed by the WHO [33], the upsurge of *Aedes* mosquitoes may be due  
348 to the southwestern monsoon (end of May to September), which brought a higher frequency of  
349 precipitation and higher humidity and temperature, and therefore, a higher breeding rate for the  
350 mosquitoes. Second, a minimum centralized vector control program can be conducted due to  
351 the stay-at-home policy. It is relevant to any method that is intended to reduce dengue  
352 incidences by reducing, but not eliminating, *Aedes* mosquito populations. Before that,  
353 researchers [34] have associated the index of the temporal vector with dengue occurrence, and  
354 the relationships between *Aedes* mosquito density and DENV transmission indexes for *Ae.*  
355 *aegypti* density are correlated with the prevalence of human dengue infections but are relatively  
356 weakly correlated with the incidences, indicating that other factors were involved in  
357 determining the incidence pattern. This is supported by the participant during the *Aedes* survey  
358 when a fogging activity was observed on May 28, 2020 (phase 5 – conditional movement  
359 control order), and total *Ae. albopictus* was significantly lower on May 29, 2020 (Fig. 5), but  
360 the mosquitoes caught afterward remained elevated in general.

361 Furthermore, our findings showed the presence of both *Ae. aegypti* and *Ae. albopictus*  
362 from an indoor environment but no *Ae. aegypti* from the outdoors, indicating that *Ae. albopictus*  
363 is better adapted to a sudden change in the environment, such as the duration of lockdown when  
364 most of the hosts shift to the indoors. With the consistent growth rate of the indoor and outdoor  
365 populations, we postulate that *Ae. albopictus* invades the habitat of *Ae. aegypti* and showed a  
366 high possibility of colonizing the habitat. Our result is consistent with Nur Aida et al. [35] and  
367 Dieng et al. [15], who found that they could increase the invasiveness of *Ae. albopictus* by  
368 obtaining a high number of egg and mosquito counts from the indoor environment of Penang  
369 Island. Previous studies [11, 13, 36] from other countries have also reported the aggressive  
370 invasive behavior of *Ae. albopictus*, which shared the habitat with other native or existing  
371 mosquitoes, including *Ae. aegypti*, which are commonly predominant in indoor environments  
372 [37]. Due to the restriction of traveling during the period of lockdown, our results provided  
373 limited area coverage, but when considering the scale of the study as a semifield assessment,  
374 the results propose a few important discoveries of vector distribution and occurrence during  
375 the MRs of lockdown.

376

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379

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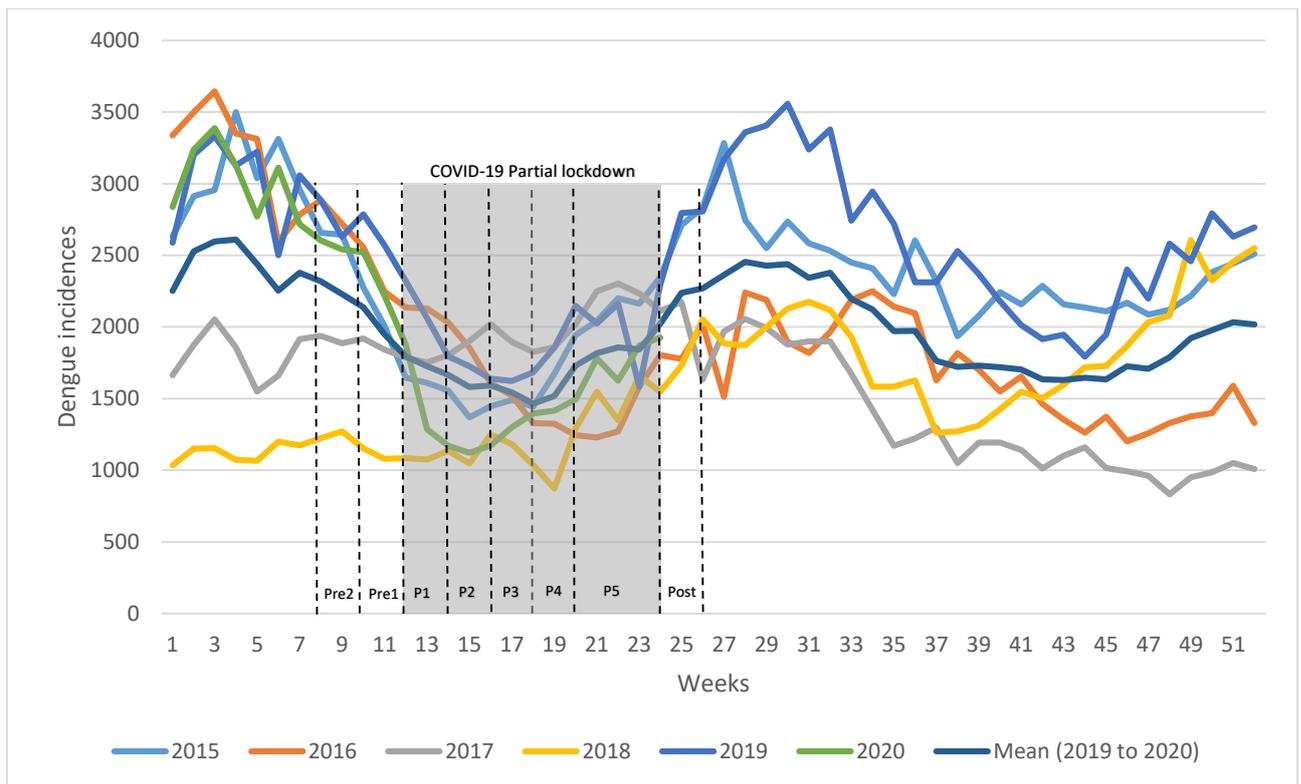
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506 **Fig 1. Dengue endemic growth from years 2015 to June of 2020.** Eight stages: Pre-  
507 lockdown 2; Pre1, Pre-lockdown 1; P1, Phase 1; P2, Phase 2; P3, Phase 3; P4, Phase 4; P5,  
508 Phase 5; Post, Post-lockdown

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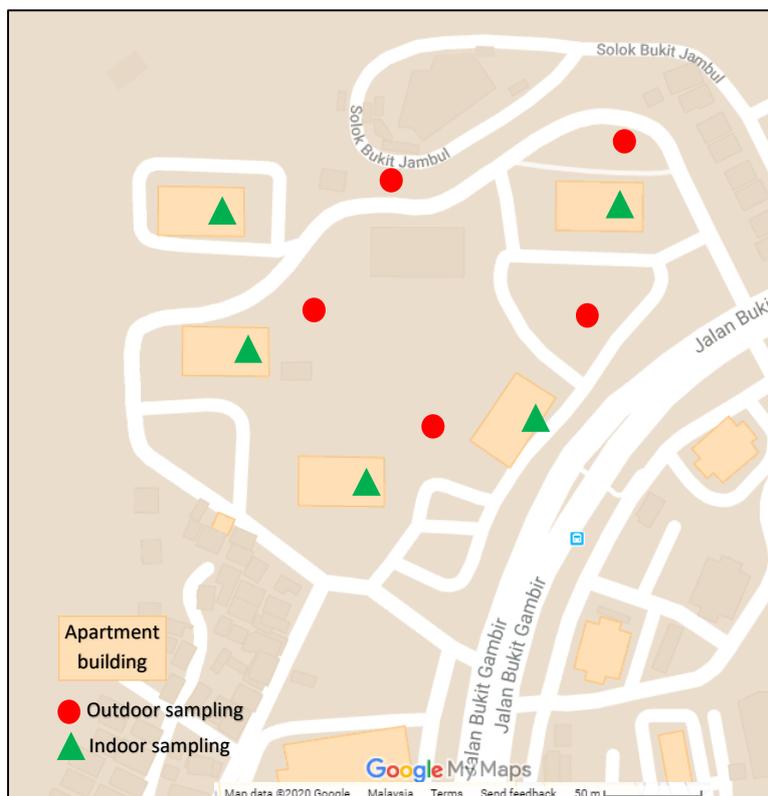
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526 **Fig. 2 Sampling locations at Taman Bukit Jambul, Penang Malaysia**

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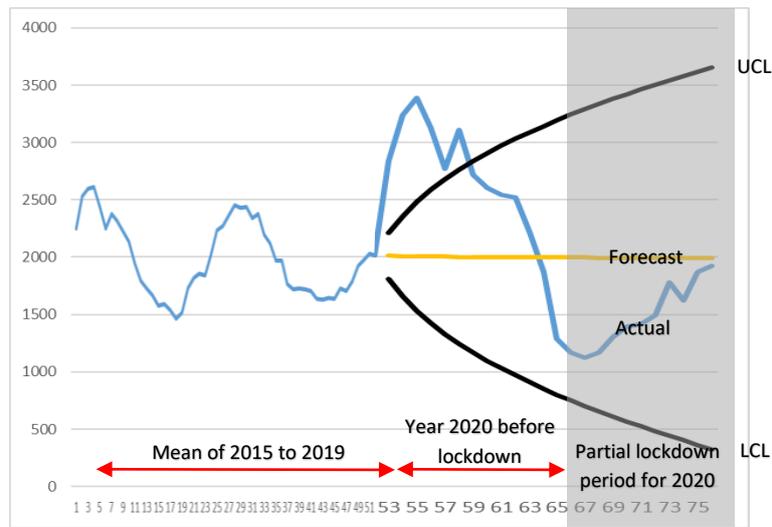
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544 **Fig. 3 Simulation of dengue incidence by using mean of 2015 to 2019 weekly incidences**  
545 **and correlation between the simulated and the actual trend before and the duration of**  
546 **partial lockdown. ULC, upper confidence level; LCL, lover confidence level.**

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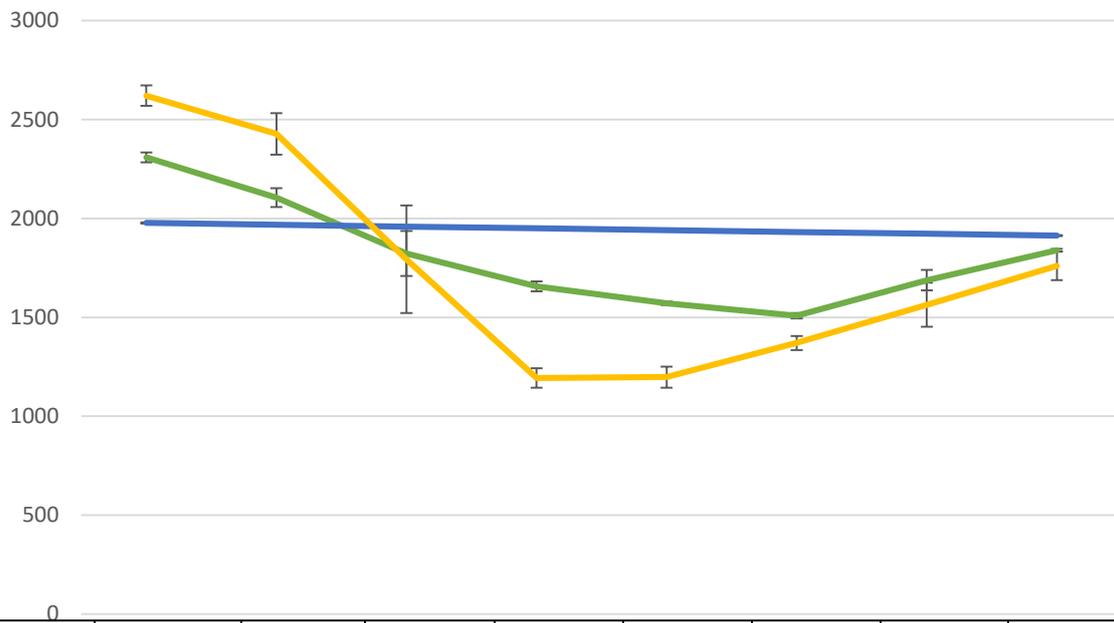
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	Pre-LD-2	Pre-LD-1	P1	P2	P3	P4	P5	Post-LD	SLOPE
Mean (year 2019 to 2020)	-74.1	-140.6	-111.2	-73.2	-19	-11.9	149.5	13.6	
Simulation	-0.22	-0.22	-0.22	-0.22	-0.22	-0.22	-0.22	-0.22	
Year 2020	-88	-161	-466	-83	90	57	183.5	44.5	

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**Fig. 4 Analysis of variance (ANOVA) of dengue incidences of mean, simulation and year 2020 for eight stages of COVID-19 partial lockdown in Malaysia and the slope for the stages.** Pre-LD-2, Pre-lockdown-2; Pre-LD-1, Pre-lockdown-1; P1, Phase 1; P2, Phase 2; P3, Phase 3; P4, Phase 4; P5, Phase 5; Post-LD, post-lockdown.

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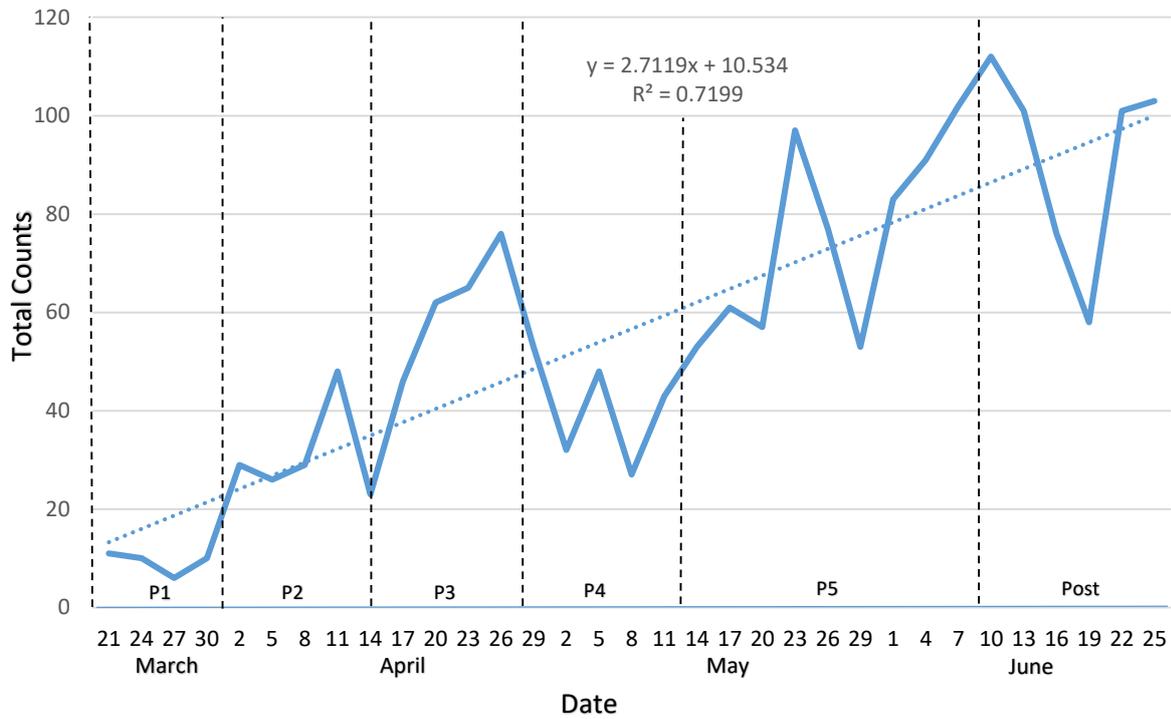
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**Figure 5 Total counts of *Aedes albopictus* for the dates and phases of COVID-19 partial lockdown at the outdoor environment of sampling location.**