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**Trade-off between climatic and human population impacts on *Aedes aegypti* life history
shapes its geographic distribution**

Tarteel Abdalgader^{1,2}, Michael Pedersen³, Dongsheng Ren⁴, Guiquan Sun⁵, Lai Zhang^{1,†}

¹School of Mathematical Science, Yangzhou University, Yangzhou 225002 China

²Department of Mathematics, Faculty of Education, University of Khartoum P. O. Box 321, Sudan

³Department of Applied Mathematics and Computer Science, Technical University of Denmark,
DK-2800, Denmark

⁴National Institute for Communicable Disease Control and Prevention (China CDC), Beijing
102206 China

⁵Department of Mathematics, North University of China, Taiyuan 030051 China

[†]Corresponding author, email: lai.zhang@yzu.edu.cn

16

17 **Abstract** The annual death statistics due to vector-borne diseases transmitted by *Aedes* mosquitoes
18 cause a still growing concern for the public health in the affected regions. An improved
19 understanding of how climatic and population changes impact the spread of *Aedes aegypti* will help
20 estimate the future populations exposure and vulnerability, and is essential to the improvement of
21 public health preparedness. We apply an empirically well-investigated process-based mathematical
22 model based on the life cycle of the mosquito to assess how climate scenarios (Representative
23 Concentration Pathways (RCP)) and socioeconomic scenarios (Shared Socioeconomic Pathways
24 (SSP)) will affect the growth and potential distribution of this mosquito in China. Our results show
25 that the risk area will expand considerably, increasing up to 21.46% and 24.75% of China's land
26 area in 2050 and 2070, respectively, and the new added area lies mainly in the east and center of
27 China. The population in the risk area grows substantially up to 2050 and then drops down steadily.
28 However, these changes vary noticeably among different combinations between RCPs and SSPs
29 with the RCP2.6*SSP4 yielding the most favorable scenario in 2070, representing approximately
30 14.11% of China's land area and 113 cities at risk, which is slightly lower compared to 2019. Our
31 results further reveal that there is a significant trade-off between climatic and human population
32 impacts on the spreading of *Aedes aegypti*, possibly leading to an overestimation (underestimation)
33 in sparsely (densely) populated areas if the populations impact on the mosquito's life history is
34 unaccounted for. These results suggest that both climate and population changes are crucial factors
35 in the formation of the populations exposure to *Aedes*-borne virus transmission in China, however, a
36 reduced population growth rate may slow down the spread of this mosquito by effectively
37 counteracting the climate warming impacts.

38

39 **Keywords** *Aedes aegypti*, vector-borne disease, climate change, representative concentration
40 pathways, socioeconomic pathways.

41 **Introduction**

42 Dengue fever (DF) is the world's second-most severe vector-borne disease after malaria in terms of
43 annual mortality and morbidity, leading to approximately 20,000 deaths every year (Beatty, 2008;
44 Ferreira, 2012). The primary vector for the virus that causes DF is the mosquito *Aedes aegypti*
45 (WHO *et al.*, 2009), which is usually found in tropical and subtropical zones in urban areas where
46 larvae and pupae can exploit the artificial water-filled containers (Tabachnick and Powell 1979).
47 Besides DF, *Aedes aegypti* also transmits Chikungunya, Zika, and yellow fever. Its susceptibility to
48 the rapid spreading as well as the increased disease burden has long made *Aedes aegypti* a global
49 public health concern (Jentes *et al.*, 2011; Kraemer *et al.*, 2015a).

50 China reported the first DF outbreak in the southeast coastal region in the 1940s. No cases were
51 recorded after that until 1978 when the second outbreak occurred in Foshan, Guangdong province.
52 Thereafter DF quickly spread to other southern provinces such as Guangxi, Hainan, Fujian,
53 Zhejiang, and Yunnan (Guo *et al.*, 2018; Li *et al.*, 2010; Wu *et al.*, 2010; Zhang *et al.*, 2014) and
54 further northward to the central China (e.g., Henan Province) in 2013 (Huang *et al.*, 2014). During
55 the past few years of this century, China recorded more than 50,000 cases of DF in more than ten
56 provinces (Sun *et al.*, 2017). The current geographical range of *Aedes aegypti* in China is mostly in
57 the south in Hainan, Guangdong, and the southwest of Yunnan province (Liu *et al.*, 2019). It is one
58 of the fastest spreading viral diseases, however, there is no effective vaccine available nor effective
59 antiviral remediation to prevent DF (Ferreira, 2012; Wilder-Smith *et al.*, 2010). Hence, disease-
60 vector surveillance and control measures have become more critical in order to prevent the
61 transmission of this disease, particularly in the context of simultaneous climate change (Iwamura *et*
62 *al.*, 2020).

63 A wide variety of studies have investigated the effect of climate change on the geographic
64 expansion of *Aedes aegypti* as well as the possibility of other *Aedes*-borne virus transmission by
65 means of statistical vector-distribution models (e.g., Bhatt *et al.*, 2013; Khormi and Kumar 2014;
66 Liu *et al.*, 2019; Rogers *et al.*, 2014; Ryan *et al.*, 2019; Tjaden *et al.*, 2017a). While these

approaches are helpful in describing the patterns of the relationship between vector occurrences and climate-related environmental conditions, a mechanistic modelling of such a relationship has been surprisingly less considered (Iwamura *et al.*, 2020). Nonetheless, process-based mechanistic models can be achieved by incorporating causal relationships, such as experimental observations of vector development under different climate conditions, including the time-dependent influence of climate, natural environment, and human population growth (e.g., Liu-Helmersson *et al.*, 2019a, 2019b).

In addition to climate change, socioeconomic pathways have been used to describe the possible consequences for public health, particularly in order to predict the health impacts under different degrees of climate change and development patterns (Ebi, 2014). This is mainly because *Aedes aegypti* is an urban vector where the habitation sites are rarely found more than a hundred meters away from human houses and they feed almost entirely on human blood, making human beings perfect hosts (Ponlawat and Harrington, 2005; Reiter, 2007). However, very few studies have used the projected human population growth scenarios in a mechanistic modelling framework in order to estimate the future populations exposure to *Aedes aegypti*, an important research gap since a growing number of primarily statistical studies have suggested the crucial role of socioeconomic changes in the predictions of the development of climate-related vector-borne diseases (e.g., Kraemer *et al.*, 2019; Messina *et al.*, 2019; Monaghan *et al.*, 2018; Rohat *et al.*, 2020, Liu-Helmersson *et al.*, 2019b).

In this paper, we apply a process-based mathematical model based on the life cycle of *Aedes aegypti* and combine both climatic and human population changes into the prediction of the development of *Aedes aegypti* in the future of China. We aim to estimate the invasion risk area and the size of human population in the risk area, and we illustrate the geographical distribution changes under the interplay between four RCPs and five SSPs scenarios. We expect that climatic and human factors interactively shape the expansion of *Aedes Aegypti* but a strong trade-off between them is anticipated.

93 **Methods**

94 The mathematical model employed is based on the life cycle of *Aedes aegypti* (Yang *et al.*, 2014). It
 95 has three life-stages: larvae (L), pupae (P), and adults (A), and each life stage is represented by an
 96 ordinary differential equation to describe the rates of change on the mosquito population size in
 97 time (Liu-Helmersson *et al.*, 2019a):

$$\begin{aligned}\frac{dL}{dt} &= \Phi h A q f - \mu_l L - \sigma_l L, \\ \frac{dP}{dt} &= \sigma_l L - \mu_p P - \sigma_p P, \\ \frac{dA}{dt} &= \sigma_p P - \mu_a A.\end{aligned}$$

99 Here, adult female mosquitoes feed on human blood in order to lay eggs at a rate of Φh , where Φ is
 100 the oviposition rate per female mosquito, measured in the laboratory with a full blood meal
 101 provided (Fig. S1 in Supporting Information), and h is the human blood meal factor depending on
 102 the population density. A fraction q of the laid eggs are viable and develop into larvae, among
 103 which a fraction f will become female. Mosquitoes die at a rate μ_l , μ_p and μ_a in each of the three life
 104 stages, respectively, and moreover, experience a transition rate of σ_l (σ_p) from larvae (pupae) to
 105 pupae (adult). The physiological rates of mortality, stage transition and oviposition are
 106 environmentally dependent (i.e., temperature and/or precipitation, Fig. S2), and measured in the
 107 laboratory in controlled temperature experiments (Yang *et al.*, 2009, 2014). A detailed model
 108 description can be found in Helmersson *et al.* (2019a), and also in Supporting Information.

109 The potential of *Aedes aegypti* to establish itself in a new area is assessed by estimating the vector
 110 population growth rate over a one year period, and it is determined by the Floquet exponent through
 111 the following system (Liu-Helmersson *et al.*, 2019a)

$$\begin{pmatrix} L' \\ P' \\ A' \end{pmatrix} = \begin{pmatrix} -\sigma_l - \mu_l & 0 & \Phi h q f \\ \sigma_l & -\sigma_p - \mu_p & 0 \\ 0 & \sigma_p & -\mu_a \end{pmatrix} \begin{pmatrix} L \\ P \\ A \end{pmatrix}.$$

113 A positive population growth rate means the mosquito population size will expand spatially and
114 multiply over each period, and the mosquito will eventually establish itself in the area. In this case
115 we designate the area with a positive growth rate as a suitable environment for *Aedes aegypti*.
116 Otherwise, the mosquito population size will continue to decrease until it fades away. We calculated
117 the growth rate numerically using MATLAB and Arc GIS 10.8 was used to map risk areas for each
118 city of China (Fig. S3).

119 For the presence records of *Aedes aegypti*, the occurrence data were from the National Institute
120 for Communicable Disease Control and prevention (China CDC) in 2019 at the county level and
121 from a global occurrence point datasets in Kraemer *et al.*, 2015b. The collected occurrence data
122 were regrouped at the city level. The associated climate and human population data in 2019 were
123 obtained from the Climate Projection Center (CPC) and National Bureau of Statistics of China,
124 respectively.

125 For climate changes, the individual mean daily temperature and precipitation for each city in
126 China were projected from the five global circulation models (Taylor *et al.*, 2011) under the four
127 RCPs scenarios in 2050 and 2070 for China (Fig.S4 and Fig.S5). While these predicted data show a
128 differentiation among cities, they represent a spatial average within each city. The projected average
129 daily temperature by 2050 and 2070 will increase under all RCPs (Fig.1A), except for the RCP2.6,
130 in which it will slightly decrease by $\cong 0.1^{\circ}\text{C}$ from 2050 to 2070. The average daily precipitation
131 will decrease steadily under all RCPs by 2050, followed by a slight change in 2070 except for the
132 sharp change under the scenario RCP8.5 (Fig. 1B).

133 For the future human population changes, the individual predicted population for each city in
134 China under the five SSPs scenarios in 2050 and 2070 were collected from the National Center for
135 Atmospheric Research (NCAR) (Fig.S6). The total population number shows a significant
136 downward trend in the coming years of this century (Chen *et al.*, 2020) under all scenarios of SSPs
137 with diverging rates (Fig. 1C). The population projection for the for SSP3 is the highest (Samir and

138 Lutz, 2017), but almost indistinguishable for SSP1 and SSP5. It is worth mentioning that there is a
 139 significant variation in the population number among the studied cities in China (Fig. 1D and S6).

140
 141 **Fig.1** The projected temperature (A) and precipitation (B) under the four RCPs, and human
 142 population growth under the five SSPs (C) in 2050 and 2070, (D) the average population number
 143 over cities considered in China as well as the standard deviation under the five SSPs.

145 Results

146 The model was validated by comparing the model output (*Aedes aegypti* growth rate in 2019) to the
 147 occurrence records of *Aedes aegypti* in China. As shown in Fig. 2, predicted environmental
 148 suitability for this species was generally found in the southern provinces such as Guangxi,
 149 Guangdong, Yunnan and Hainan. Our model further shows that additional regions (e.g., Fujian,
 150 Jiangxi) might also be suitable for mosquito infestation, but were not reflected in the database. This
 151 is very likely due to the incomplete mosquito survey and/or surveillance and insufficient

152 adaptability of this mosquito to temperate climates, compared to its competitor *Aedes albopictus*
 153 (Rezza 2012). In addition, the absent records may also be due to non-successful dispersal into
 154 currently environmentally suitable areas. However, among the 15 cities with a reported occurrence
 155 of *Aedes aegypti*, we found that 14 (93.3%) of them have a positive growth rate and only 1 (6.7%)
 156 has a negative growth rate. Moreover, the vast majority (87%) of the occurrence records falls in
 157 cities with daily growth rate greater than 0.02. Therefore, our model could broadly reproduce the
 158 current known distribution of *Aedes aegypti* in China.

167 **Fig.2** Comparison between model outputs of *Aedes aegypti* growth rate (color areas) in 2019 and
 168 presence records of *Aedes aegypti* (blue dots).

170 The future projections of geographical distribution and suitable environment (positive growth
 171 rate) of *Aedes aegypti* when combining both climate and population changes in 2050 and 2070 are,
 172 respectively, shown in Fig. 3 and Fig. 4. Apparently, future changes in climate and population will
 173 facilitate the invasion of *Aedes aegypti*, consequently rendering more people potentially vulnerable
 174 to *Aedes*-borne diseases. The risk area (measured by number of cities) and population size at risk
 175 are summarized in **Fig. 5**, and their interpretation unfolds as follows.

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Fig.3 The projected baseline (2019) and future (2050) geographic distribution of *Aedes aegypti* in China under different combinations of RCPs and SSPs. The four colors represent non-risk areas (gray), risk areas in the reference year of 2019 (yellow), emergent risk areas in 2050 (red), and vanished risk areas in 2050 (green).

182

183 **Fig.4** The projected baseline (2019) and future (2050) geographic distribution of *Aedes aegypti* in
 184 China under different combinations of RCPs and SSPs. The four colors represent non-risk areas
 185 (gray), risk areas in the reference year of 2019 (yellow), emergent risk areas in 2070 (red), and
 186 vanished risk areas in 2070 (green).

187

188 ***Projections of risk area***

189 The area suitable for *Aedes aegypti* will expand under all combinations of RCPs and SSPs in both
 190 2050 and 2070 albeit to various extents, with a minor exception for RCP2.6. For example, the

number of cities (million km²) at risk is projected to be 126 (1.548), 137(1.656), 132(1.606), and 154(1.869) in 2050 (**Fig. 5A**), but 116(1.4), 135(1.630), 139(1.682), and 177(2.162) in 2070 (**Fig. 5C**) under the four climate scenarios and SSP1. In general, the most suitable climate scenario for *Aedes aegypti* is RCP8.5 whereas the least is RCP2.6. Interestingly, population changes can mitigate the impact of future climate on the growth of *Aedes aegypti*, particularly for RCP2.6 and RCP4.5, under which the projected risk area slightly decreases from 2050 to 2070. This is due to the decreased human population growth rate (Fig. 1C), which results in less blood meal and consequently lower fecundity rate (Fig.S1A and S1B). Noticeably, risk area steadily expands for all SSPs under RCP8.5, and this is primarily because the daily temperature and precipitation are projected to rise by 1.1°C and 0.1 mm from 2050 to 2070, respectively, under RCP8.5 (Fig. 1A, B).

Projection of human population at risk area

There is a slight decrease in the population at risk in 2050 for some combinations between SSPs and RCPs compared to 2019 (Fig. 5B). Furthermore, there is a remarkable drop in the population number at risk from 2050 to 2070 for all RCPs. However, the growth of the population number at risk occurs only under SSP3, which leads to the largest number of 770 million, but merely 29 million more than the number in 2050 under the same scenarios (RCP8.5*SSP3). Overall, the tendency in population at risk is consistent with the decline in the predicted population change from 2019 to 2050 and further on to 2070 (Fig. 1C). It is worth mentioning that the most significant decline in the population number occurs under SSP4 (Fig. 5D), being 383(RCP2.6)-593(RCP8.5) millions in 2070 and a reduction of 143(RCP2.6)-33(RCP8.5) millions relative to 2050, and a reduction of 192(RCP2.6) millions relative to 2019.

Fig.5 The projections of number of cities and human population at risk of *Aedes aegypti* in China under different combinations of RCPs and SSPs in 2050 (A and B) and in 2070 (C and D), respectively. The horizontal dashed lines indicate the associated numbers in 2019.

Predicted changes in geographic distribution

The future geographic distribution of *Aedes aegypti* under SSP4 (SSP3) are illustrated in Fig. 6 (Fig. S7) for two cases: climate change considered as a sole factor and both climate and human population changes accounted for. In the former case, populations of the cities studied were kept the same as in 2019. Apparently, all cities in the south and southeast of China will become environmentally suitable for the growth of *Aedes aegypti* in these two cases (Table. S3). However, the projected number of cities in the centre, southwest and west (Fig. S9) is higher for the former case (climate change only) than for the other, whereas the opposite situation occurs in the east. A remarkable feature is that a large part of cities predicted to be at risk when only climate change is considered, turn out to be safe when SSPs scenarios were involved in prediction, which is particularly evident in the southwest. The increased number of cities in the east is very likely linked to the high human population density in this region (Fig. S6).

230

231 **Fig.6** The future projections of geographical distribution changes of *Aedes aegypti* in China when
 232 considering climate changes only under four RCPs (red dots) and when combining both climate and
 233 human population changes for SSP4 under four RCPs (blue color) in 2050 and 2070.

234

235 Discussion

236 The surveillance of arboviral vectors is required for the control and prevention of vector-borne
237 diseases, and existing studies suggested that future climate change will significantly influence the
238 expansion and distribution of *Aedes aegypti* (Khormi and Kumar, 2014; Ryan *et al.*, 2019). Here,
239 we applied a process-based mathematical model combining both future climate and human
240 population changes to predict the environmental suitability of *Aedes aegypti* infestation in China.
241 Our model is an extension of a previous model (Liu-Helmerssne *et al.*, 2019a) by incorporating
242 predicted population patterns into the mosquito's life history traits. This incorporation makes our
243 model advantageous over previous models where predicted population patterns were merely used to
244 estimate future population vulnerability and nearly independent of the mosquito's life history
245 (Monaghan *et al.*, 2018; Kraemer *et al.*, 2019; Messina *et al.*, 2019; Rohat *et al.*, 2020), in terms of
246 minimizing skewed estimates of climatic impacts across different SSPs.

247 Our study has underpinned that climate change plays an important role in driving the expansion
248 of *Aedes aegypti*. With increased carbon emission in the future, the predicted risk area may grow up
249 to 16.27% (RCP2.6) to 21.5% (RCP8.5) by 2050 and to 14.21% (RCP2.6) to 24.75% (RCP8.5) by
250 2070. Moreover, the risk area is widely distributed in the south, southeast, east and the centre, and
251 in some parts of the west and the southwest, including more high-latitude areas that were previously
252 uninfected. Our prediction further shows that it remains safe in the north, northeast, and the
253 northwest (e.g., such as Xinjiang, Tibet, Inner Mongolia, Heilongjiang, etc), where mean daily
254 temperature and precipitation decrease as we head north and population density remains low (Fig.
255 S6). These results are basically corroborated by the evidence-based study of increased dengue cases
256 and expanded affected areas in recent years in China (Sun *et al.*, 2017), and further agree with the
257 recent study by Fan and Liu (2019) based solely on RCP scenarios in China and with studies from
258 other countries/continents including United States (Butterworth *et al.*, 2017), Tanzania (Mweya *et*
259 *al.*, 2016), Korea (Lee *et al.*, 2018), and Europe (Liu-Helmerssne *et al.*, 2019b). All together, these
260 studies collectively show that the expansion trend of *Aedes aegypti* is almost the same in different

261 countries all over the world, a shift from low-latitude areas to high-latitude areas.

262 In addition to climate factors, human population contributions to the expansion of *Aedes aegypti*
263 and future population exposure to *Aedes*-borne virus might also be of large importance (Rohat *et al.*,
264 2020). Our model revealed that a future human population change significantly influences the
265 climate-based predictions (Fig. 5 and Fig. S7), which is fairly evident in the southwest and the east
266 of China (Fig. S8 and Table S3). A prominent example is that the annual growth rate of *Aedes*
267 *aegypti* will be 0.21 in case of combining both climate and population changes in some cities (e.g.,
268 Aomen, Xianggang, Dongguang, Shenzhen in 2070), but only 0.13 if we consider only climate
269 changes. Hence, the potential of promoting *Aedes aegypti* infestation in a climatically suitable
270 environment may be undermined by insufficient human blood due to low population density (e.g.,
271 the southwest, Fig. 5). Conversely, the reduced infestation potential in an environmentally less
272 friendly region can be compensated by high blood-mediated fecundity rate (e.g., the east). The
273 crucial role of population changes has also been strongly emphasized by a couple of previous
274 studies using projected population patterns and climate changes to assess the future population
275 exposure to *Aedes*-borne virus from non-mechanistic perspectives (Monaghan *et al.*, 2018; Kraemer
276 *et al.*, 2019; Messina *et al.*, 2019; Rohat *et al.*, 2020). Taken together, the future distribution of
277 *Aedes aegypti* will be substantially impacted by the interplay between climatic and human factors.

278 An important implication of such interplay is that it may generate a strong trade-off between the
279 climatic and population impacts on *Aedes aegypti* infestation among different regions in China. This
280 trade-off may further induce a considerable burden of contagious and chronic climate-related health
281 effects, making effective surveillance of arboviral vectors even more challenging. While the entire
282 population declines, albeit to different degrees depending on the socioeconomic pathways (Fig. 1C),
283 there is a strong variation in the human population numbers between different cities (Fig. 1D). In
284 general, densely populated cities are distributed along the coastal areas (Fig. S6), and climatic
285 impacts are very likely to be dominant in these areas. On the other hand, population impacts
286 possibly dominate in the southwest of China (e.g., Yunnan, Guangxi and Sichuan). A recent

climate-based prediction of the expansion of *Aedes aegypti* in European cities demonstrated that large parts of southern Europe might be at risk (Liu-Helmersson *et al.*, 2019a). However, this prediction must be applied with caution as future population information is completely lacking. A more recent study with a mechanistic phenology model predicted that climate change may accelerate the invasion potential of *Aedes aegypti* in both North America and China (Iwamura *et al.*, 2020). Our results imply that this prediction might be overestimated due to the declined population density in the future, particularly in the west and north of China, even though climatic advantages remain prominent.

An interesting result in our study is the considerable decline in vulnerable population in 2070, irrespective of the socioeconomic pathways and carbon emission future (Fig. 5D) with an exception under RCP8.5*SSP3, relative to 2050. Areas at risk will also experience a small decline especially under the lowest carbon emission future (RCP 2.6). These declines are primarily attributed to the continuous decrease in population (Fig. 1C) since temperature is predicted to rise uninterruptedly (Fig. 1A). The best outcome for China is the prediction under RCP2.6*SSP4, which shows that approximately 14.11% of China's land area and 113 cities will be at risk, which is slightly lower relative to 2019. However, being a developing country, the more feasible strategy for China might be to achieve a modest carbon emission future (e.g., RCP2.6 and RCP4.5) and socioeconomic pathways other than SSP3, which is only slightly severer than RCP2.6*SSP4.

Taken together, our model provides a road map into the spatial-temporal expansion of *Aedes aegypti* that is expected to accompany climate and human population changes synergistically acting on the *Aedes* mosquito's life history traits. In spite of our model validation using regional data (i.e., China), the uncovered mechanism is applicable globally in that the trade-off between climatic and human population impacts on *Aedes aegypti*'s infestation considerably regulates the spatial expansion of this species. There might be more areas over the globe becoming climatically suitable in the future (Liu-Helmersson *et al.*, 2019a, 2019b; Iwamura *et al.*, 2020), but the areas with low population density may remain safe. Moreover, the predicted spatial spatial-temporal distribution of

313 *Aedes aegypti* can be used to inform where and when new invasions of the mosquito are likely to
314 occur in China, and thus help more effectively and indicatively plan for disease vector surveillance
315 and control before an introduction of dengue virus leading to thousands of dengue cases, which is
316 particularly relevant for areas with high population density.

317 However, our model suffers from the following limitations. First, the model did not account for
318 the impacts of *Aedes albopictus* on the prediction of population vulnerability. *Aedes aegypti* and
319 *Aedes albopictus* are two major vectors responsible for the spread of dengue fever, but the former
320 species is more dependent on human behavior in order to evolve (Eisen et al., 2014). Nonetheless,
321 the interspecific interaction between these two species might mitigate the rate and extent of range
322 expansion of *Aedes aegypti* (Braks et al., 2004). Second, our model assumed a simplified
323 environment condition where temperature, precipitation and human population density are
324 responsible for the spreading of *Aedes aegypti*. In reality, several other factors such as land cover
325 and use, habitat fragmentation, and income may interactively affect its spreading. For example,
326 regions with high income are usually associated with good sanitation condition, which is helpful in
327 reducing *Aedes*' oviposition rate, thus inhibiting its spreading accordingly (David et al., 2009,
328 Viennet et al., 2016). In contrast, expansion of land cover and use such as urbanization may
329 facilitate *Aedes*' invasion (Mackenzie et al., 2004). While integrating these factors into our model is
330 very likely to enhance the precision of model prediction, it is challenging to obtain highly reliable
331 predicated data associated with these factors, and data of poor reliability may add more
332 uncertainties to model prediction. Finally, the increased globalization and improved transportation
333 network may also aid *Aedes*' spreading (Behrens et al., 2013, Kraemer et al., 2019), which is,
334 however, ignored in the present work.

335 In conclusion, we found that future climate changes facilitate the growth and expansion of *Aedes*
336 *aegypti* in the future of China, rendering a larger population vulnerable to vector-borne diseases.
337 The future geographic distribution of *Aedes aegypti* and vulnerable human population will increase
338 significantly till 2050, covering a large area of China's mainland, except to the north, but then

steadily decline afterwards, mainly attributed to a human population decline. Most importantly, our model reveals a trade-off between climatic and human population impacts on the spatial expansion of *Aedes aegypti*. Consequently, climate-based modelling work may suffer from an overestimation of the environmental suitability for *Aedes aegypti* development in regions with profitable climatic environment and low population density, but from an underestimation in regions with non-profitable climatic environment and high population density. However, if measures are not taken to reduce greenhouse gas concentration, reduced population may be unable to effectively counteract the climatically driven expansion of *Aedes aegypti* in China, particularly under the scenario RCP8.5.

Author contributions: LZ conceived this study and developed the model. TA carried out the analytical analysis, and performed the numerical simulations. TA, MP and LZ wrote the manuscript draft. All authors discussed the results and contributed to the final text.

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None of the authors have a conflict of interest to declare.

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