1 Short communication

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3 **Plagues of Desert Locust: No invasion risk to China**

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20 **Abstract**

21 Recently, the most serious upsurge of desert locust (*Schistocerca gregaria*) in the last 25
 22 years is spreading across eastern Africa and southwestern Asia. Parts of the desert locust
 23 'invasion area', namely the northern border areas of Pakistan and India are very close to
 24 China, and whether locust swarms will invade China is of wide concern. To answer this
 25 question, we identified areas of potentially suitable habitat for the desert locust within
 26 China based on historical precipitation and temperature data, and found that parts of
 27 Xinjiang and Inner Mongolia provinces could provide ephemeral habitat in summer, but
 28 these places are remote from any other desert locust breeding area. Presently, the desert
 29 locust populations in Pakistan and India are mature and have laid eggs, and are less likely
 30 to spread long distances. The next generation of adults will appear in April and May, and
 31 so we examined twenty years' historical wind data (2000–2019) for this period. Our results
 32 showed that winds at the height of locust swarm flight blew eastward during April and May,
 33 but the wind speeds were quite slow and would not facilitate desert locust eastward
 34 migration over large distances. Furthermore, simulated trajectories of desert locust
 35 swarms with 10 days' migration mostly ended within India. The most easterly point of
 36 these trajectories just reached eastern India, close to the border between India and
 37 Myanmar, and this is very close to the eastern border of the invasion area of desert locust
 38 described in previous studies. In conclusion, the risk that the desert locust will invade
 39 China is very low.

40 **Keywords:** *Schistocerca gregaria*; Insect migration; Trajectory simulation; Locust upsurge;
 41 Invasion risk

Desert locust, *Schistocerca gregaria*, is one of the most devastating migratory pests in the world [1-4]. It is highly mobile and feeds on large quantities of any kind of green vegetation, including crops, pasture, and fodder [1-4], and even a moderate swarm measuring 10 km² would eat some 1000 tons of vegetation daily. Recently, the most serious upsurge of desert locust since the last serious outbreak in 1994–1995 is spreading across eastern Africa and southwestern Asia. From the figures published by FAO in early February 2020, more than 280,000 ha in 13 countries were infected, and the infected area is still increasing as the locust swarms spread [5]. Among the “Invasion areas” defined from earlier studies [1], the northern borders of Pakistan and India are very close to China [5]. China is struggling to control fall armyworm (*Spodoptera frugiperda*), a migratory pest that invaded China via India and Myanmar last year [6], and consequently, whether desert locust swarms will invade China is of wide concern.

To answer this question, we first checked whether there are potentially suitable habitats for desert locust within China. Previous studies showed that (i) the desert locust is well-adapted to live in arid and semi-arid habitats where annual precipitation is roughly between 0–400 mm [7], and at least 20 mm of rain falling in a short period (or its equivalent in run-off) is required for egg development [1]; (ii) the air temperature range for egg and hopper (nymph) development is between 20–35 °C [4]; and (iii) if there is more than seven days at 10 °C, egg mortality is considerably increased [8]. Thus, we derived the 20 years’ (2000–2019) mean annual precipitation from the Climate Prediction Center Merged Analysis of Precipitation data, and 20 years’ (2000–2019) mean monthly air temperature from National Centers for Environmental Prediction (NCEP)/National Center

64 for Atmospheric Research (NCAR) reanalysis data. The mean annual precipitation data
65 showed that most areas in South Asia, Southeast Asia and East Asia are too wet for desert
66 locust persistence (annual rainfall ≥ 400 mm), such as most of India, Myanmar and most of
67 China (Fig. 1). In China, only in parts of Xinjiang, Inner Mongolia, Tibet and Qinghai
68 provinces, the annual rainfall is ≤ 400 mm. But the mean air temperature in the
69 Qinghai-Tibet Plateau is still quite cold in July (≤ 20 °C). Further, in most areas of China,
70 the mean air temperature in January is ≤ 10 °C (fig. 1), and this shows that most areas of
71 China are too cold for desert locusts to survive in winter. Taking this information together,
72 only parts of Xinjiang and Inner Mongolia provinces could conceivably be suitable habitat
73 for the desert locust in China, and these would just be ephemeral habitats in summer.

74 Although we found there are few suitable habitats for desert locust in China (see
75 above paragraph), there might be still a notional threat if the swarms from the border
76 between Pakistan and India enter China. However, the Himalayan mountains exceed
77 7000 m, and form a natural barrier stopping all or almost all insect migration -- this is
78 particularly likely with desert locusts as the lowest air temperatures (in the absence of sun)
79 at which sustained swarm flight begins is 23-24°C, and even in continuous bright sunshine
80 flight does not begin at air temperatures much below 17°C [1]. Thus, the only possible
81 route that desert locust swarms could move eastward and enter the Yunnan province of
82 China is by crossing India and Myanmar. Gregarious swarms can spread at low-level near
83 the ground or at high-level at hundreds of meters above ground (during strong convection)
84 in daytime, while spend the night roosting in vegetation [2,4]. The low flights often occur
85 during rather cool, overcast weather or in the late afternoon. Locust low fliers can stabilize

86 their ground speed at about 4.0 m/s by varying their air speed and heading direction
87 according to the wind speed, and thus they can move up to 150 km in one day by 10-hr
88 sustained flying [2,4]. The straight distance from the Pakistan-India border to Yunnan
89 province is about 3000 km. Swarms from this region would need 20 days' sustained flying
90 to cover this distance if they just keep flying at lower level near ground, and this is quite
91 impossible.

92 The desert locust swarms also can travel over hundreds and thousands of kilometers
93 by riding high-level winds, for example from North-West Africa to the British Isles in 1954
94 and from West Africa to the Caribbean, a distance of 5,000 km in about ten days, in 1988
95 [9]. High-flying swarming locusts do not have any single preferred orientation and turn
96 back towards the center of the swarm when they reach the edges in order to maintain
97 swarm cohesion. Thus, the speed and direction of swarm displacement is the same as the
98 wind at the height of flight [1,2,9,10]. So, we then checked whether there are suitable
99 winds at high level (about 1500 m above ground) to carry locust eastwards. Long-range
100 swarm migration is more likely to happen before sexual maturity [2,10]. At this moment,
101 the swarms in Pakistan and India are mature and have laid eggs, and are thus less likely
102 spread over long distances. In this region, the mean temperature in February, March and
103 April in last 20 years is $21.07 \pm 0.16^{\circ}\text{C}$, $26.93 \pm 0.14^{\circ}\text{C}$ and $32.30 \pm 0.10^{\circ}\text{C}$, respectively.
104 Based on the relationship between air temperature and the desert locust development
105 [2,4,8], the next generation of locust adults will appear in April and May, after about 30
106 days as eggs and 30-40 days as hoppers. We thus focused on the period in April and May,
107 and analyzed 20 years' (2000–2019) historical climatic data derived from NCEP/NCAR

108 reanalysis data. We found that the winds at 850 hPa level (about 1500 m above sea level)
 109 blew consistently toward the east during daytime in these two months (Rayleigh test; April:
 110 mean value 88 °, $r = 0.58$, $P < 0.0001$, $n=600$; May: 80 °, $r = 0.76$, $P < 0.0001$, $n=620$; the
 111 r -value is a measure of the clustering of the angular distribution from 0 to 1), but the wind
 112 speed is quite slow (April: 3.32 ± 0.07 m/s (mean value $\pm$ standard error (S.E.)), $n=600$;
 113 May: 4.23 ± 0.08 m/s, $n=620$) (Fig. 2). As the desert locust cannot fly when the air
 114 temperature at flight altitude is below 20 °C [see above, 1,9], we also identified the area of
 115 air temperatures at 850 hPa level ≥ 20 °C in late April and late May (Fig. 2). The area with
 116 a suitable temperature for locust swarm flight covered most of India, Myanmar and
 117 Bangladesh, but in China only Yunnan province was suitable. Therefore, it is conceivable
 118 that the desert locust might reach Yunnan province but cannot fly further north in China by
 119 windborne migration in April and May.

120 Lastly, we modelled the long-distance migration of the desert locust with the Hybrid
 121 Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model of the National
 122 Oceanic and Atmospheric Administration (NOAA) [11]. This model is designed for
 123 computing three-dimensional trajectories of air parcels and applied extensively to study
 124 migratory trajectories of many insect species [12]. Here, we made the following
 125 assumptions for the trajectory simulation of the desert locust: (i) the speed and direction of
 126 its displacement is the same as the wind at its flight height; (ii) daytime flying occurs mostly
 127 from 0900 a.m. (local time, i.e. 0300 UTC) to 1900 a.m.; (iii) locusts cannot fly at air
 128 temperatures below 20°C; and (iv) long-distance flight can be sustained for up to 10 days.
 129 Because we do not have the meteorological data for April and May in this year (2020), we

130 used the meteorological conditions at flight altitude from the past 5 years (2015–2019). In
131 total, 305 forward trajectories starting from a point at the border between Pakistan and
132 India (27°N, 70°E) were calculated (Fig. 3). Most trajectories went eastwards, and the
133 endpoints were located east of the startpoint (Rayleigh test; April: mean value 90°, $r = 0.91$,
134 $P < 0.0001$, $n=150$; May: 95°, $r = 0.94$, $P < 0.0001$, $n=151$). Due to the slowness of the
135 winds, migration distances were quite short (April: 917.3 ± 16.9 km; May: 1116.1 ± 11.5
136 km), and most trajectories ended within India (Fig. 3). All these results indicate that it is
137 impossible for desert locust to reach China by 10 days' windborne migration.

138

139 **Conclusions**

140 The distribution of desert locust is very well known and, during plagues, it can cover the
141 arid and semi-arid region from the Atlantic coast of West Africa to eastern India. The most
142 easterly distribution during invasion periods reaches eastern India and Bangladesh but
143 does not include any part of China [1,4]. The potentially suitable area identified in this
144 study was based on an annual precipitation ≤ 400 mm and mean air temperature in
145 January $\geq 10^\circ$, and this area is consistent with the desert locust 'recession area', that is,
146 the area occupied when there are few, if any, swarms present [1,4,7]. In China, only parts
147 of Xinjiang and Inner Mongolia provinces could provide ephemeral habitat in summer, and
148 these regions are far away from any other desert locust breeding area. In the past, only
149 one individual of the solitaria form of desert locust was detected in Zhangmu District,
150 Nyalam County in Tibet (location at about 28.33° N, 86°E, elevation; 2250 m) on 29 April
151 1974, and this place is on the southern slope of the Himalayan Mountains [13]. During

152 April and May, the winds at height of about 1500 m above sea level blow eastward, but the
153 wind speed is quite slow. In our trajectory simulations, most trajectories with 10 days'
154 migration ended within India, and the furthest just reached eastern India, or close to the
155 border between India and Myanmar. The most easterly point of our trajectories is almost
156 the same as the eastern border of the invasion area of desert locust described in previous
157 studies [4,7]. In conclusion, it is very unlikely that agriculturally-significant populations of
158 the desert locust will invade China.

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Figures 1–3

Fig. 1: Mean annual precipitation (filled color), 10 °C isotherm in January (blue dotted line) and 20 °C isotherm in July (blue solid line) averaged for 20 years (2000–2019). Potentially suitable habitat for the desert locust should, at least, satisfy conditions with an annual precipitation ≤ 400 mm and air temperature in July $\geq 20^{\circ}\text{C}$. As eggs cannot survive when the temperature is below 10°C , for year-round breeding the temperatures in winter should be above 10°C . Taking all these things together, only small areas in Xinjiang and Inner Mongolia provinces could provide an ephemeral (summer) habitat for the desert locust in China. TB-Tibet, YN-Yunnan, QH-Qinghai, IM-Inner Mongolia.

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215 **Fig. 2: Mean wind (vector arrows) and temperature (the area filled with light red is $\geq 20^{\circ}\text{C}$ on**
 216 **30 April or 31 May, and green dashed line is on 20°C isotherm on 1 April or 1 May) conditions**
 217 **at 850 hPa (about 1500 above sea level) in April and May in last 20 years (2000–2019).**
 218 **Subplots in (c) and (d) show the histogram distribution of wind direction and wind speed in**
 219 **the border between Pakistan and India (indicated by blue circles). The grey filled area shows**
 220 **the Qinghai-Tibet Plateau.**

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222
223 **Fig. 3: Simulated forward trajectories started from a point at the border between Pakistan**
224 **and India (27°N, 70°E) in last 5 years (2015–2019). These trajectories were calculated by the**
225 **Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model.**