# Modelling the distribution of *Aedes aegypti* and *Aedes albopictus*

# using climate, host density and interspecies competitive effects

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53    **ABSTRACT**

54    Florida faces the challenge of repeated introduction and autochthonous transmission

55    of arboviruses transmitted by *Aedes aegypti* and *Aedes albopictus*. Empirically-

56    based predictive models of the spatial distribution of these species would aid

57    surveillance and vector control efforts. To predict the occurrence and abundance of

58    these species, we fit mixed-effects zero-inflated negative binomial regression to a

59    mosquito surveillance dataset with records from more than 200,000 trap days,

60    covering 73% of the land area and ranging from 2004 to 2018 in Florida. We found

61    an asymmetrical competitive interaction between adult populations of *Aedes aegypti*

62    and *Aedes albopictus* for the sampled sites. Wind speed was negatively associated

63    with the occurrence and abundance of both vectors. Our model predictions show

64    high accuracy (72.9% to 94.5%) in the validation tests leaving out a random 10%

65    subset of sites and data from 2018, suggesting a potential for predicting the

66    distribution of the two *Aedes* vectors.

67

**INTRODUCTION**

*Aedes* mosquitoes, in particular, *Aedes aegypti* (Linnaeus) and *Aedes albopictus* (Skuse), are the primary vectors of multiple arboviruses including dengue virus (DENV), Zika virus (ZIKV), yellow fever virus, and chikungunya virus (CHIKV)(Bargielowski and Lounibos, 2016; Kotsakiozi et al., 2017; Lounibos and Kramer, 2016). The incidence of these viruses in humans is driven, in part, by the close overlapping habitats of humans and these vectors (Charrel et al., 2014). In the absence of effective vaccines, reducing contact between mosquitoes and humans through targeted mosquito control is regarded as the most effective approach to reduce risk of mosquito-borne arbovirus transmission. There have been several efforts to create large-scale estimates of the spatial presence and abundance of these vectors using a variety of collection methods and data from literature reports and entomological surveys of mosquito occurrence. Global maps have been generated using climate and socio-economic variables, relying on a strong dependence of mosquito populations to temperature and rainfall (Brady et al., 2014; Kraemer et al., 2015b; Leta et al., 2018). These efforts have uncertainty associated with publication bias and variability of collection methods. Large-scale data collected by standardized surveillance methods could improve the certainty and precision of occurrence and abundance maps. Here, we use a dataset covering around 102,000 $km^2$ (73%) and more than 200,000 trap days spanning 17 years of observation (Figs 1 and S7). We built a mixed-effects zero-inflated negative binomial (ZINB) model to characterize and predict the occurrence and abundance of *Ae. aegypti* and *Ae. albopictus*, simultaneously using climate and human population density data.

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92   Florida has suffered from the introduction and autochthonous transmission of DENV

93   (Muñoz-Jordán et al., 2013; Teets et al., 2014), CHIKV (Kendrick et al., 2014) and

94   ZIKV (Grubaugh et al., 2017; Likos et al., 2016) and remain at high risk of

95   transmission due to repeated pathogen introductions, high densities of *Ae. aegypti*

96   and *Ae. albopictus* (Kraemer et al., 2015b) and favorable meteorological conditions

97   (Grubaugh et al., 2017; Monaghan et al., 2016). Studies have shown a positive

98   relationship between human Zika and dengue cases and larger *Ae. aegypti*

99   populations in urban areas (Bowman et al., 2014; Grubaugh et al., 2017). Therefore,

100   characterizing the population size of the two *Aedes* species over time and space

101   could aid in examining the risk of local arbovirus transmission and spread in Florida

102   and inform more effective and targeted mosquito control efforts.

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104   Although coexistence of the two *Aedes* vectors is reported (Lounibos et al., 2016),

105   declining populations and displaced habitats of *Ae. aegypti* have been observed in

106   several places, including Florida (Bagny et al., 2009; Kaplan et al., 2010; Lounibos

107   and Kramer, 2016; O'Meara et al., 1995). In particular, the habitats of *Ae. aegypti*

108   were restricted to urban areas while those of *Ae. albopictus* were found to increase

109   in suburban and rural areas in Florida (Lounibos, 2002). The proposed mechanisms

110   for the displacements of *Ae. aegypti* include species interactions such as the

111   superiority of *Ae. albopictus* to compete for resources at the larval stage and

112   asymmetric sterilization at the adult stage after interspecific mating which favors *Ae.*

113   *albopictus* (Bargielowski and Lounibos, 2016; Juliano, 2009; Lounibos and Kramer,

114   2016). Previous studies modelled the current spatial distribution of *Ae. aegypti* and

115   *Ae. albopictus* by applying boosted regression trees to a comprehensive global

116   database of *Aedes* occurrence (Kraemer et al., 2015a, 2015b) and characterized the

117   spatial and temporal abundance of the two *Aedes* species in a local southern Florida

118   county (Reiskind and Lounibos, 2013). However, these studies, which estimated the

119   distribution and abundance of *Aedes*, are limited because of the minimal amount of

120   data from standardized collections of mosquito populations and failure to consider

121   the species interactions between *Ae. aegypti* and *Ae. albopictus* (Lounibos and

122   Juliano, 2018). Additionally, inconsistent findings on the associations between their

123   distribution and meteorological factors were reported according to a recent

124   systematic review (Sallam et al., 2017).

125

126   The objective of this study was to simultaneously characterize the occurrence and

127   abundance of the *Ae. aegypti* and *Ae. albopictus* mosquitoes using the routine

128   mosquito surveillance data in Florida. To estimate if mosquitoes were present or not

129   and if present, the number of adults in each trap location, a mixed-effects zero-

130   inflated negative binomial (ZINB) regression was performed. Different predictors or

131   factors were examined, like climate and human population density covariates, and

132   the potential interaction between *Ae. aegypti* and *Ae. albopictus* based on their

133   spatial and temporal abundance. Predictions on occurrence of *Ae. aegypti* and *Ae.*

134   *albopictus* from models were assessed with and without abundance information to

135   determine if real-time predictions based solely on climate data and human population

136   density information provided accurate predictions.


137   **RESULTS**

138   In total, the longitudinal training dataset included132,088 weekly records from 1,246

139   unique sites for *Ae. aegypti* and *Ae. albopictus*, respectively, covering 33 out of 67

140   counties. The dataset includes 53% of the land area in Florida and from 2004 to

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141     2018 (Table 1, Figs. S1, S2 and S5). Traps were typically set for one day but a

142     minority of collaborators reported counts from a trap that was set for multiple days

143     (7.4%). Approximately 87.4% and 84.8% of trap episodes reported no adults

144     collected for *Ae. aegypti* or *Ae. albopictus*, respectively. The majority (81.4%) of

145     traps used were light traps, and the remaining 7.3% and 11.3% of traps used were

146     BG Sentinel traps or other mosquito traps (Table S4), respectively (Table 1) (see

147     more details for traps in the supplementary). A wider range and higher trap rate was

148     reported for *Ae. albopictus* compared to *Ae. aegypti* in Florida, and as expected from

149     previous studies, most *Ae. aegypti* were reported in southern Florida (Figs. 1 and

150     S1). Both *Ae. aegypti* and *Ae. albopictus* were trapped more often between May to

151     October (Fig. S1 and S2). The median human population density of the locations

152     where the traps were set is 480.8 persons per $km^2$ (Interquartile range (IQR), 112.5

153     to 1165.2 $km^2$) (Fig S3). The median weekly average wind speed was 5.4 meter per

154     second (IQR, 4.5 to 6.6 m/s), and the median relative humidity was 76.7% (IQR, 73.1

155     to 80.1 %) (Fig S3).  The minimum temperature of the trap episodes ranged from

156     18.7 to 25.8 °C with median of 23.0 °C. The median difference of predicted

157     maximum temperature on minimum temperature was 0 °C (IQR, -0.5 to 0.5 °C) (Fig

158     S3).

159     **Presence and abundance of *Aedes***

160     The results from ZINB regression suggested the probability of presence of *Ae.*

161     *aegypti* and *Ae. albopictus* in the current week was positively associated with the

162     previous presence of its own species and the other species (Table 2). The

163     abundance of both *Aedes* species was more likely to be higher if a higher

164     abundance was reported for its own species (e.g. Incidence rate ratio (IRR) 1.03 and

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165    1.02 for one week prior for the two vectors, respectively) (Table 2). The abundance

166    of *Ae. aegypti* was negatively associated with the abundance of *Ae. albopictus* in the

167    last three weeks (IRR: 0.992, 0.994 and 0.990 for one, two and three weeks earlier,

168    respectively), while the abundance of *Ae. albopictus* seemed to be not associated

169    with the previous abundance of *Ae. aegypti* (Table 2).

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171    We found both the presence (Odds ratio (OR): 0.98, 0.95 to 1.01 and 0.97, 0.95 to

172    0.99, respectively) and abundance (IRR: 0.97, 0.96 to 0.99 and 0.97, 0.95 to 0.98,

173    respectively) of *Ae*. *aegypti* and *Ae. albopictus* were negatively associated with the

174    average wind speed of the week. Minimum temperature was positively associated

175    with the occurrence (OR: 1.01 for *Ae*. *aegypti* and 1.08 for *Ae. albopictus*) and the

176    abundance (IRR: 1.13 and 1.09 respectively) of both species. Maximum temperature

177    was found to be negatively associated with the occurrence of *Ae. aegypti* (OR: 0.91,

178    0.87 to 0.95) but positively associated with the occurrence of *Ae*. *albopictus* (OR:

179    1.04, 1.00 to 1.08) (Table 2). We found the relative humidity was negatively

180    associated with the abundance of *Ae. aegypti* (IRR: 0.99, 0.98 to 1.00) and the

181    occurrence of *Ae. albopictus* (IRR: 0.99, 0.98 to 0.99). Model estimates using NOAA

182    climate data were similar with our main results, except for the positive associations

183    between maximum temperature and the abundance and presence for both species

184    (Table S1). Greater precipitation was positively associated with the abundance for

185    both *Ae. aegypti* (IRR: 1.42, 1.26 to 1.59) and *Ae. albopictus* (IRR: 1.09, 0.99 to

186    1.20), but not associated with the probability of presence (OR: 0.85, 0.69 to 1.05 and

187    1.05, 0.94 to 1.19, respectively) (Table S1).

188

189    Both the probability of presence (OR: 0.95, 0.94 to 0.97) and abundance (IRR: 0.98,

190    0.97 to 1.00) of *Ae. albopictus* were negatively associated with a higher human

191    population density, while the probability of the presence of *Ae. aegypti* was positively

192    associated with human population density (OR: 1.05, 1.03 to 1.07). We also found

193    substantial heterogeneities of presence and abundance of these two *Aedes* species

194    across trap sites and counties (Table 2). The greatest heterogeneity was found with

195    the presence at a county level for both *Ae. aegypti* (random effects (RE): 12.27) and

196    *Ae. albopictus* (RE: 6.592)*.

197    **Performance of model fits to the longitudinal training dataset**

198    We compared the predictions from the main ZINB model with observed presence

199    and abundance from the longitudinal training datasets (Fig. 2 and Fig. S6). Overall,

200    our model fits well with both the occurrence and abundance estimates for *Ae.*

201    *aegypti* and *Ae. albopictus* (Fig. 2). We observed that 91.1% and 84.9% of the

202    predicted presence was consistent with the observed presence of *Ae. aegypti* and

203    *Ae. albopictus*, respectively. Similarly, 83.8% and 77.0% of the predicted abundance

204    was correlated with the observations, while 90.1% and 86.5% of the predicted

205    abundance differed by ±1 per trap day from the observations (Fig. 2C-D). The values

206    of Moran's I are 0.47 ($p < 0.01$) and 0.08 ($p = 0.02$) for *Ae. aegypti* and *Ae.*

207    *albopictus*, respectively, and is -0.03 ($p = 0.81$) for *Ae. aegypti* after removing data

208    from Miami-Dade. Temporal differences were relatively larger during May and

209    September, when the observed average trap rates were also higher, for both species

210    (Fig. S6).

8

**Performance of model in validation sets**

211    For both spatial (Fig. 3A) and temporal (Fig. 43) test datasets, the model predictions

213    are highly consistent with the observed presence of both *Ae. aegypti* (AUC: 0.93 and

214    0.92 for spatial and temporal predictions, respectively) and *Ae. albopictus* (AUC:

215    0.84 and 0.81 for spatial and temporal predictions, respectively). Overall, 86.2% and

216    82.1% of the predicted abundance were consistent with the observations for the

217    spatial prediction of *Ae. aegypti* and *Ae. albopictus* (Fig. 3B-C), respectively, while

218    72.9% and 94.5% of the predictions were correct for the temporal predictions (Fig.

219    3E-F).

221    We fit another ZINB model to the longitudinal training dataset without using

222    information on the previous presence and abundance of both species, and applied

223    the model to predict the no abundance testing dataset, which failed on the four

224    consecutive four-week criteria. The no abundance testing dataset has total 45,535

225    trap episodes collected from 2,791 unique sites in 48 counties (Figs. S4 and S5).

226    The model provided good predictions in both presence (AUC: 0.90 for *Ae. aegypti*

227    and 0.85 for *Ae. albopictus*) and abundance (82.8% and 70.2% right predictions,

228    respectively) for the two *Aedes* species (Fig. S7).

230    Using our models, we predicted the number of *Ae. aegypti* and *Ae. albopictus* that

231    would be expected to be found in traps in all points in the state. Fig. 4 shows

232    predictions created using the "no abundance model" for August 1, 2018 incorporating

233    random effects representing systematic differences in surveillance by county (Fig. 4

234    A and B) and only incorporating fixed effects (Fig. 4 C and D). BG traps were

235   assumed to be used for all sites. Predictions in Fig. 4 present our estimates

236   attempting to eliminate the impact of systematic differences in surveillance.


237   **DISCUSSION**

238   We built models using more than 132,000 routine mosquito surveillance records from

239   33 counties in Florida collected from 2004 to 2018, to characterize and predict the

240   occurrence and abundance of *Ae. aegypti* and *Ae. albopictus*. Our model performed

241   well, particularly considering the stochastic nature of mosquito populations, trap

242   efficiency and small-scale trap locations. We modelled random effects across sites

243   and counties to account for inconsistencies and randomness and found the highest

244   random effect was for the probability of presence at the county level, suggesting

245   great heterogeneity of occurrence across counties possibly down to differences in

246   surveillance and domestic mosquito control across counties.

247

248   Our results suggest a broad distribution of *Ae. albopictus* in Florida, while *Ae.*

249   *aegypti* was more likely to be found in counties in southern Florida, a pattern similar

250   to reports during the past two decades (Lounibos et al., 2016). This is also consistent

251   with previous observations about the declining population of *Ae. aegypti* after the

252   invasion of *Ae. albopictus* in the Southern United States (Bonizzoni et al., 2013;

253   Lounibos, 2002). However, there is some evidence to suggest limited local

254   recoveries of *Ae. aegypti* in relation to *Ae. albopictus*, in part, attributable to evolution

255   of resistance to satyrization (Bargielowski et al., 2013; Bargielowski and Lounibos,

256   2016; Hopperstad and Reiskind, 2016; Lounibos et al., 2016). Our findings on the

257   positive association between the probability of presence of adult mosquitoes of the

258   two *Aedes* species suggest their niches have some overlap particularly in urban

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259    areas (Lounibos and Juliano, 2018). This is supported by the observed coexistence

260    of *Ae. aegypti* and *Ae. albopictus* in Florida (Bonizzoni et al., 2013; Lounibos and

261    Kramer, 2016; Reiskind and Lounibos, 2013) and the similar breeding behavior of

262    the two species (Hashim et al., 2018). We also found evidence of competitive

263    interactions between the two species. The abundance of *Ae. aegypti* was negatively

264    associated with the previous abundance of *Ae. albopictus*, with the greatest effect

265    size observed for the abundance of *Ae. albopictus* during the previous three-week

266    period. A previous study revealed the breeding preference of *Ae. aegypti* in habitats

267    without *Ae. albopictus* (Hashim et al., 2018). Our findings support the hypothesis that

268    the two *Aedes* species can coexist but the abundance of adult *Ae. aegypti* are

269    suppressed due to its failure to outcompete at the larval stage and/or the impact of

270    interspecific mating (Bargielowski et al., 2013; Juliano, 2009; Lounibos and Kramer,

271    2016). Evolution of resistance to interspecific mating (i.e., satyrization-resistance) in

272    *Ae. aegypti* populations is likely to promote coexsistence.(Bargielowski and

273    Lounibos, 2016) Future control efforts targeting the *Aedes* species, especially *Ae.*

274    *albopictus*, need to take into account the risk of resurgence of *Ae. aegypti*, which has

275    been documented in Brazil (Kotsakiozi et al., 2017) , and can be possible in Florida

276    considering recent reports of the rapid evolution of satyrization-resistant *aegypti*

277    (Bargielowski and Lounibos, 2016), coupled with an observed increased in

278    insecticide resistance as compared to Ae. *albopictus* (Estep, et al., unpublished)

279    ("Distribution Maps – Florida Mosquito Information," n.d.).

280

281    We found the presence and abundance of *Ae. albopictus* are negatively associated

282    with human population density, while the presence of *Ae. aegypti* was positively

283    associated with the human population density, which matches with reports that

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284  anthropophilic *Ae. aegypti* are more likely to be found in urban areas and the *Ae.*

285  *albopictus* has wider range of habitats including peri-urban, vegetated and rural

286  areas (Lounibos and Kramer, 2016; Metzger et al., 2017), mostly due to its wide

287  range of host preference and a greater adaptation to different climates (Bonizzoni et

288  al., 2013). Land cover status, which is an important predictor of distribution of these

289  species by other reports (Kraemer et al., 2015b; Rey et al., 2006), was not included

290  in our main analysis as it may be associated with the human population density and

291  the vast majority of the *Ae. aegypti* were collected in developed areas with a large

292  human presence, consistent with other studies (Rodrigues et al., 2015; Tsai and

293  Teng, 2016). The observed positive association between human and *Ae. aegypti*

294  density has practical implications for targeted mosquito control because these areas

295  represent the greatest risk for arboviral infections (e.g., dengue(Padmanabha et al.,

296  2012)).

297

298  Major presence of both species between May to October has also been reported

299  previously and corresponds to Florida's rainy season and associated availability of

300  breeding sites, and abiotic factors such as temperature (Reiskind and Lounibos,

301  2013). Related to this, the negative association between wind speed and the

302  presence and abundance of both species analysis can include some explanations

303  such as high wind speed hindering the effective trapping of the mosquitoes;

304  therefore, traps are more likely to have no or fewer collections of mosquitoes during

305  windy days. Also, mosquito activity and therefore host-seeking have been shown to

306  be affected by higher wind speeds; presumably due to the combined effect of

307  affected flight distance and pattern as well as the poor dispersal of the $CO_2$ plume for

308  both short and long distances.

309

310 Our results suggest positive associations between temperature and observed

311 abundance of adult *Ae. aegypti* and *Ae. albopictus* when using the NOAA data, while

312 inconsistent findings on the association between maximum temperature and the

313 abundance of *Ae. aegypti* was found when using the NASA data. A study suggested

314 higher tolerance of low temperature in adult *Ae. aegypti* compared to *Ae. albopictus*,

315 leading to a relatively lower mortality of adult *Ae. aegypti* in low temperature and a

316 milder effect of temperature on the presence of *Ae. aegypti* (Brady et al., 2013). One

317 previous study observed that *Ae. albopictus* prefer to live in cooler areas in Florida

318 (Bonizzoni et al., 2013). However, different local adaptations by these *Aedes* species

319 to climatic changes were also reported both in and outside Florida (Lounibos and

320 Kramer, 2016; Muttis et al., 2018). Despite these discussions with relation to habitat

321 and mortality of the two *Aedes* vectors and temperature, seasonality can be used to

322 predict the patterns of presence and abundance of these two *Aedes* species and the

323 incidence of diseases transmitted by the these mosquito vectors (Monaghan et al.,

324 2016; Reiskind and Lounibos, 2013; Xu et al., 2017).

325

326 We find a negative correlation between relative humidity the abundance of *Ae.*

327 *aegypti* and the presence of *Ae. albopictus*. These findings support laboratory and

328 field observations showing climate-driven egg mortality, with greater desiccation

329 resistance of *Ae. aegypti* than *Ae. albopictus*, and species-specific responses in

330 occupancy of containers with drier conditions favoring *Ae. aegypti* (Juliano et al.,

331 2002; Lounibos et al., 2010; Mogi et al., 1996). Previous field studies have shown

332 that dry periods are associated with disproportionately greater mortality *of Ae.*

333 *albopictus* eggs than *Ae. aegypti* eggs in Florida (Juliano et al., 2002). Previous

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334      laboratory studies revealed desiccation stress on survival of adult *Ae. aegypti* and

335      *Ae. albopictus* with mortality increasing non-linearly with decreasing relative humidity

336      (Hylton, 1967; Lucio et al., 2013; Schmidt et al., 2018). The complex relation

337      between adult survival and relative humidity and the observed disproportional

338      distribution of higher relative humidity in Florida could drive the negative association

339      (Fig S3). In addition, higher relative humidity was usually associated with greater

340      precipitation, which was found to be positively correlated with the abundance of both

341      vectors, but not the probability of occurrence of the two species in the sensitivity

342      analysis (Table S2). The effect of precipitation on the abundance of these two *Aedes*

343      species was considered to be mediated by induced egg hatching in containers upon

344      flooding and promotion of vegetation after raining (Reiskind and Lounibos, 2013;

345      Sallam et al., 2017). Larger effect of precipitation on the abundance of *Ae. aegypti*

346      than of *Ae. albopictus* could be because the preference of the former to use breeding

347      in artificial containers for development of the immature stages, which are prone to

348      have more obvious influence from precipitation compared to vegetation.

349

350      The probability and efficacy of capturing *Ae. aegypti* and *Ae. albopictus* by a BG-

351      sentinel trap was found to be greater compared to light traps (Table 2), which is

352      consistent with previous findings (Li et al., 2016; Williams et al., 2006). We

353      performed a sensitivity analysis by fitting a ZINB model to data collected by BG

354      sentinel traps only and found the robustness of our main results are seemly

355      unaffected not to be affected by the spatial distribution of BG sentinel traps (Fig. S8).

356      In addition, we were not able to assess the role of attractants due to limited data

357      available, which are believed to increase the capture efficacy of mosquitoes (de

358      Ázara et al., 2013).

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360   Our model which incorporates the previous abundance of heterospecific and

361   conspecific *Aedes* species at a trap site demonstrates high accuracy in predicting

362   the presence and abundance of *Ae. aegypti* and *Ae. albopictus* (Fig. 2 and Fig. S6).

363   Analysis of long-term mosquito surveillance data is challenged by the excessive zero

364   counts, which may be real absence, absence due to trap failure or adverse

365   environmental conditions. The ZINB regression can model the two scenarios of

366   absence simultaneously. However, variability in trap placement, efficiency of specific

367   traps and other sources of variation in mosquito trapping practices may reduce our

368   model performance. Performance tended to be lower when trapping rates were

369   higher, while 97.1% (*Ae. aegypti*) and 96.8% (*Ae. albopictus*) of the differences

370   between predicted and observed trap rate were within 5 per trap-day. A larger rate of

371   inaccurate predictions was observed during months when trap rates of both

372   mosquito species were higher, corresponding to the more dispersed variance of a

373   higher trap rate. In addition, spatial autocorrelation was found for the model of *Ae.*

374   *aegypti*, which was mainly due to the high autocorrelation between observations in

375   Miami-Dade. The estimates and predictions are however not affected by the spatial

376   autocorrelation, as suggested by the model fit to the longitudinal training dataset but

377   removing data from Miami-Dade (Fig. S9 and Table S3).

378

379   Our model can be applied to predict spatial and temporal presence and abundance

380   of *Ae. aegypti* and *Ae. albopictus* with good accuracy (Fig. 3). Although great

381   variance was observed across counties and sites, we found that temporal prediction

382   was more challenging for both species. Several sites first reported the occurrence or

383   resurgence of *Ae. aegypti* in 2017, indicating the dynamic niches of the mosquitoes,

384   which hinders the distribution forecasting of the two vectors.

385

386   We found that our model performed well in external validation even without recent

387   data on each species ("no abundance model"). This suggests that accurate real-time

388   forecasts could be generated without gathering and collating abundance data in real-

389   time, giving timely predictions of the occurrence of *Ae. aegypti* and *Ae. albopictus*

390   using only site-specific meteorological and human population density data. Results

391   from the "no abundance model" incorporating fixed effects only provide homogenous

392   predictions, which are largely informed by the human population density, while the

393   empirical data however suggested great variations in the abundance captured

394   across the counties (Fig. 1). This is could be partially due to the systematic

395   differences in trapping practices and surveillance across counties and can be

396   captured by the model incorporating random effects.

397

398   Many efforts have been made to map the distribution of *Ae. aegypti* and *Ae.*

399   *albopictus* at broad regional scales, which were highly dependent on vegetation and

400   meteorological factors (Brady et al., 2014; Kraemer et al., 2015b; Leta et al., 2018).

401   Our study observes suppression of adult population of *Ae. aegypti* by *Ae. albopictus*,

402   highlighting the importance of including species interactions in future mapping work

403   as underscored by recent studies, especially when considering predictions at high

404   spatial resolution (Lounibos and Juliano, 2018). Otherwise, the distribution of *Ae.*

405   *aegypti* would likely be overestimated since the two *Aedes* vectors shared many

406   common abiotic conditions. The median changes of predicted trap rate of *Ae. aegypti*

407   in Miami-Dade are -17.0% (IQR: -21.0 to 19.3%) and -24.6% (IQR: -28.2 to 8.3%)

16

408    when the trap rate for *Ae. albopictus* was 1 and 100 per trap-night, respectively. In

409    addition, predictions from standardized longitudinal mosquito surveillance could aid

410    to refine the distribution maps of these vectors by incorporating the seasonal pattern

411    and real-time invasion activity. Finally, our empirical surveillance data can be used to

412    validate and refine the local performance of large-scale maps. Integrating

413    longitudinal surveillance could provide valuable information on absence and

414    abundance, therefore reducing the sampling bias and disproportional weighting

415    caused by presence only data (Wisz and Guisan, 2009).

416

417    There are several limitations to our study. First, our data has relatively more trap

418    episodes during April to November, when the trap rate for these two vectors was

419    often high. The estimated impact of low temperature on the presence and

420    abundance of these two *Aedes* vectors may therefore be affected. Second, more

421    than half of the records included in the main analysis are from Miami-Dade, St.

422    Johns, Polk and Pinellas counties (Table S5). We have modelled the random effects

423    across both sites and counties to account for the potential spatial variations of

424    surveillance, which may improve the generalization capability of our conclusions. We

425    were not able to characterize specific details of trap locations or other aspects of

426    sites such as details of the built environment. These details might further improve

427    forecasts.

428

429    Our models demonstrate potential for predicting the occurrence of *Ae. aegypti* and

430    *Ae. albopictus*, to better inform targeted mosquito control efforts. Model predictions

431    produced with and without the benefit of recent surveillance data were of high

432   accuracy suggesting that real-time forecasts could be produced with just climate

433   data alone.

434   **MATERIALS AND METHODS**

435   **Mosquito surveillance data**

436   Statewide surveillance data on 16 *Aedes* species was obtained by networking with

437   Florida's mosquito control districts, Clarke Scientific, the Florida Department of

438   Agriculture Consumer Services, and the Florida Department of Health. Each control

439   district is required to trap mosquitoes prior to conducting their control efforts by

440   Florida Statutes 388 and 482. The traps were placed to acquire a representative

441   sampling of the district including baseline traps placed in the same location annually,

442   at risk areas due to environmental factors like increased standing water, locations

443   within areas of known arbovirus transmission, and frequent areas of complaint.

444   Information collected from these traps includes the speciated count and life phase of

445   the trapped mosquitoes, date and duration of collection, type of trap, and coordinates

446   of the trap sites. The collected mosquitoes were speciated according to standardized

447   mosquito keys (Darsie and Morris, 2003). For missing data, the duration of collection

448   was assumed to be one day, according to the common trapping practices, and

449   coordinates were extracted from Google Maps based on the address of the site. The

450   full dataset was aggregated to include data on adult *Ae. aegypti* and *Ae. albopictus*,

451   two vectors related with arboviruses, on a week basis. The longitudinal training

452   dataset for the zero-inflated negative binomial (ZINB) regression was extracted from

453   the full dataset and included only data collected from sites with at least four

454   consecutive weeks of surveillance and no missing explanatory variables.

18

**Abiotic variables**

To examine the potential effects of meteorological factors on the trap rate of the two

*Aedes* species, temperature (℃), wind speed (meter per second) and relative

humidity (%) were included in the model. We obtained the daily meteorological data

for Florida from the NASA Prediction of Worldwide Energy Resources("NASA

Prediction of Worldwide Energy Resources.," n.d.) and applied the inverse distance

weighting method (Pebesma and Gräler, 2014) to interpolate the daily weather raster

of Florida with a 5 km ×5 km resolution. We also conducted a sensitivity analysis by

using meteorological data from National Oceanic and Atmospheric Administration

(NOAA).(National Oceanic and Atmospheric Administration, 2016) The weekly

average of weather conditions was calculated as the mean of the weather conditions

on the days the traps were collected. To account for the collinearity of the maximum

and minimum temperature, we used the residuals of the linear regression of

maximum temperature on minimum temperature as a proxy of the maximum

temperature in the model, which was calculated as $\Delta T_{max} = T_{max} - (\alpha + \beta T_{min})$,

where $T_{max}$ and $T_{min}$ denoting the observed maximum and minimum temperature,

respectively, while $\alpha$ and $\beta$ were estimated from the linear regression. The

urbanization was modelled by including data on human population density, which

was obtained from Center for International Earth Science Information Network with a

5 km ×5 km resolution (SEDAC and CIESIN, 2015). If the value was missing for a

site, we extracted the corresponding environmental variables based on its coordinate

and used the average drawn from a 5km buffer around the site.

**Statistical methods**

19

478    We applied a ZINB regression model to the weekly abundance of *Ae. aegypti* and

479    *Ae. albopictus* from the longitudinal training dataset, respectively, to account for the

480    excessive zeros in the abundance data and the over-dispersed count of trapped

481    mosquitoes, simultaneously. The ZINB model comprises a binary component

482    (corresponding to the absence/presence of mosquitoes), and a negative binomial

483    competent (corresponding to the abundance of mosquitoes). The estimates from the

484    binary component (presented as odds ratio, OR) and the negative binomial

485    component (presented as incidence rate ratio, IRR) represent the associations

486    between the potential factors and the occurrence and abundance of these *Aedes*

487    vectors, respectively. The potential factors included in the ZINB model for both

488    species are: the previous abundance of *Ae. aegypti* and *Ae. albopictus* up to three

489    weeks prior, weekly site-specific meteorological factors (i.e. wind speed, maximum

490    and minimum temperature and relative humidity), human population density and type

491    of mosquito traps. We examined the potential interaction between *Ae. aegypti* and

492    *Ae. albopictus* by examining the relationship between the current abundance of one

493    species with the previous abundance of another species. We used counts of each

494    species detected in recent weeks to predict future weeks. To do this, we only

495    considered records when data was available for four consecutive weeks prior. Trap

496    type was included as an explanatory covariate as each of the traps used has a

497    different effectiveness in trapping each species. We also included the random effects

498    at both site level and county level, which were modelled for both components of

499    ZINB model simultaneously. The detailed equations used for ZINB model are

500    provided in the Supplementary information. Parameters were estimated by

501    maximizing the likelihood using "glmmTMB" package (Brooks et al., 2017) in R

502    version 3.5.0 (R Foundation for Statistical Computing, Vienna, Austria).

503

504   The model fitting was tested by comparing the observations with the predictions of

505   occurrence and abundance from the longitudinal dataset. We assessed the spatial

506   pattern by calculating the site-specific mean of residuals. The absence and presence

507   were assigned as 0 and 1 respectively for calculation purposes. Moran's I was

508   calculated to assess the spatial autocorrelation (Bivand and Piras, 2015). We

509   examined the temporal pattern of the model fitting by assessing the monthly 2.5%

510   and 97.5% quantiles of the difference between the predicted and observed

511   abundances for the two *Aedes species*.

512

513   We tested the prediction performance of the model both spatially and temporally.

514   Prediction of a test set was based on a model fit from a training set and comparing

515   the predicted and observed occurrence and abundance. In the spatial prediction, we

516   randomly selected records from 127 (around 10% of total) sites to be the spatial

517   testing set and used the records from the remainder of the sites as a spatial

518   validation training set (Fig. S5). In the temporal prediction, we used data up to the

519   year of 2017 as the temporal validation training set to predict data after 2017 (Fig.

520   S5). The area under the receiver operating characteristic (AUC) was used to

521   measure the performance of prediction on the mosquito occurrence. In addition, we

522   also fit a ZINB model to the longitudinal training dataset without using information on

523   the previous presence and abundance of *Ae. aegypti* and *Ae. albopictus* ("no

524   abundance model") and applied the "no abundance model" to an external no

525   abundance testing dataset comprised of the surveillance records in the full dataset

526   and failed on the four consecutive four-week criteria (Fig. S5).

527

**AUTHOR CONTRIBUTIONS**

B.Y., B.A.B. and D.A.T.C. designed the study. B.Y., B.A.B. and D.A.T.C. wrote the first draft of the manuscript. B.W.A., R.R.D., G.E.G., M.U.G.K., R.C.R.Jr., H.S., and

552 D.L.S. critically reviewed the manuscript. B.Y. performed the statistical analysis. B.Y.

553 and B.A.B. collated the mosquito data. C.K.B., P.B., J.B., K.D., J.T.D., D.D., J.M.F,

554 S.L.F., R.H., D.F.H., A.H., A.J., B.K., E.L., K.J.L., J.M., R.M., W.P., M.T.R., J.P.S.,

555 A.S., J.S., C.V., K.F.W. and R.D.X. provided and facilitated the collection of mosquito

556 surveillance data. All authors contributed substantively to the revising and editing of

557 the final draft.

558 **Conflict of interests**

559 The authors declare no competing financial interests.

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755

756

**TABLES**

**Table 1**. Characteristics of surveillance of *Aedes aegypti* and *Aedes albopictus* in Florida, 2004-2018.

| Characteristic | Number (%) | |
| --- | --- | --- |
| | **Longitudinal training dataset** | **No abundance testing dataset** |
| **Number of Counties** | 33 | 48 |
| **Number of Sites** | 1,246 | 2,791 |
| **Number of Trap-days** | 235,677 | 57,469 |
| **Records** | 132,088 | 45,535 |
| *Aedes aegypti* | | |
| Absence | 115,447 (87.4%) | 39,384 (86.5%) |
| Presence | 16,641 (12.6%) | 6,151 (13.5%) |
| *Aedes albopictus* | | |
| Absence | 112,021 (84.8%) | 35,667 (78.3%) |
| Presence | 20,067 (15.2%) | 9,868 (21.7%) |
| **Trap Types** | | |
| Light trap | 107,571 (81.4%) | 31,176 (68.5%) |
| BG Sentinel | 9,518 (7.2%) | 5,648 (12.4%) |
| Other trap types | 14,999 (11.4%) | 8,711 (19.13%) |

**Table 2**. Estimates of odds ratio (OR) and incidence rate ratio (IRR) from mixed-effects zero-inflated negative binomial analysis *Aedes aegypti* and *Aedes albopictus* in Florida, 2004-2018.

| Variables | Aedes aegypti | | Aedes albopictus | |
|---|---|---|---|---|
| | OR (95% CrI†) | IRR (95% CrI†) | OR (95% CrI†) | IRR (95% CrI†) |
| **Previous *Ae. aegypti* abundance/presence** | | | | |
| Trap rate in week *t-1* | 2.46 (2.19, 2.76)* | 1.03 (1.02, 1.03)* | 1.21 (1.10, 1.34)* | 1.00 (1.00, 1.01) |
| Trap rate in week *t-2* | 2.36 (2.11, 2.65)* | 1.03 (1.03, 1.03)* | 1.42 (1.28, 1.57)* | 1.00 (0.99, 1.00) |
| Trap rate in week *t-3* | 1.84 (1.64, 2.07)* | 1.02 (1.01, 1.02)* | 1.04 (0.94, 1.15) | 1.00 (1.00, 1.01) |
| **Previous *Ae. albopictus* abundance/presence** | | | | |
| Trap rate in week *t-1* | 1.30 (1.16, 1.47)* | 0.99 (0.99,1.00)*† | 2.48 (2.32, 2.65)* | 1.02 (1.02, 1.03)* |
| Trap rate in week *t-2* | 1.44 (1.29, 1.62)* | 0.99 (0.99,1.00)*† | 2.19 (2.05, 2.35)* | 1.02 (1.01, 1.02)* |
| Trap rate in week *t-3* | 1.28 (1.14, 1.44)* | 0.99 (0.99,1.00)*† | 1.68 (1.57, 1.80)* | 1.02 (1.01, 1.02)* |
| **Human population density (100 $persons/km^2$)** | 1.05 (1.03, 1.07)* | 1.00 (0.99, 1.02) | 0.95 (0.94, 0.97)* | 0.98 (0.97,1.00)*† |
| **Meteorology** | | | | |
| Average wind speed ($m/s$) | 0.98 (0.95, 1.01) | 0.97 (0.96, 0.99)* | 0.97 (0.95, 0.99)* | 0.97 (0.95, 0.98)* |
| Minimum temperature (℃) | 1.01 (0.99, 1.02) | 1.13 (1.12, 1.14)* | 1.08 (1.07, 1.09)* | 1.09 (1.08, 1.10)* |
| Maximum temperature (℃) | 1.12 (1.03, 1.21)* | 0.91 (0.87, 0.95)* | 1.01 (0.95, 1.06) | 1.04 (1.00,1.08)*† |
| Relative humidity (%) | 1.01 (1.00, 1.02) | 0.99 (0.98,1.00)*† | 0.99 (0.98, 0.99)* | 1.00 (0.99, 1.00) |
| **Trap type** | | | | |
| BG sentinel | Ref. | Ref. | Ref. | Ref. |
| Light trap | 0.00 (0.00, 0.01)* | 0.40 (0.31, 0.51)* | 0.77 (0.60,1.00)*† | 0.29 (0.24, 0.36)* |
| Other | 0.01 (0.00, 0.02)* | 0.20 (0.14, 0.29)* | 1.77 (1.28, 2.44)* | 0.25 (0.19, 0.33)* |
| **Random effects** | | | | |
| Site | 1.34 | 1.67 | 1.40 | 0.90 |
| County | 12.27 | 2.82 | 6.59 | 1.56 |
| **Dispersion parameter** | -- | 1.46 (1.42, 1.51) | -- | 1.13 (1.10, 1.17) |

* P < 0.05. † Credible interval. † The values with three effective digits for these estimates are (from right to left by row): 0.992 (0.987, 0.998), 0.994 (0.988, 0.999), 0.990 (0.985, 0.996), 0.984 (0.969, 0.998), 1.041 (1.001, 1.083), 0.986 (0.979, 0.994) and 0.775 (0.600, 0.999).

774    **FIGURE LEGENDS**

775    **Figure 1. Locations of traps and geographic variation in abundance of *Aedes***

776    ***aegypti* (A) and *Aedes albopictus* (B) in Florida.** Color (red for *Ae. aegypti*, blue

777    for *Ae. albopictus*) indicates mean abundance per trap day in each county. Diagonal

778    lines indicate counties without data. Inset (C) shows the location of Florida (orange)

779    in the contiguous US. Plot (D) shows *Ae. aegypti* versus *Ae. albopictus* abundances

780    in each county.

781

782    **Figure 2. Geographic variation in model predictions in occurrence and**

783    **abundance of *Aedes aegypti* and *Aedes albopictus*.** (A) Occurrence of *Ae.*

784    *aegypti*. (B) Occurrence of *Ae. albopictus.* (C) Abundance of *Ae. aegypti* . (D)

785    Abundance of *Ae. albopictus.* Average difference between predictions and

786    observations was calculated for each trap site.

787

788    **Figure 3. The performance of predictions in occurrence and abundance of**

789    ***Aedes aegypti* and *Aedes albopictus*.** (A-C) Records from 10% of trap sites were

790    randomly selected as the test set and records from the rest traps were the train set.

791    (D-F) Records from 2003 to 2016 were selected as the test set and records on and

792    after 2017 were in the train set. The model was fit to the training set and predicted

793    the test set.

794

795    **Figure 4. Maps of predicted counts of *Aedes aegypti* (red, A and C) and *Aedes***

796    ***albopictus* (blue, B and D) in August 1, 2018 in Florida.** Predictions are derived

797    from "no abundance model". Parts A and B show results incorporating random

34

798    effects representing differences in trapping counts by county. Parts C and D show

799    results only incorporating fixed effects.

800

801    **Supplementary Figure S1. Spatial and temporal distribution of mosquito**

802    **surveillance records.** A, *Aedes aegypti*. B, *Aedes albopictus*. Trap sites and

803    counties were ordered from north (upper) to south (lower). Heatmaps show weekly

804    trap rate of each trap site. The sidebars indicate whether *Aedes aegypti* or *Aedes*

805    *albopictus* had ever been reported by each site.

806

807    **Supplementary Figure S2. Weekly presence and absence of *Aedes aegypti* and**

808    ***Aedes albopictus* in Florida.**

809

810    **Supplementary Figure S3. Relations between occurrence and abundance of**

811    ***Aedes aegypti* and *Aedes albopictus* with abiotic variables.** Values at x axis are

812    the minimum, $25^{th}$ quantile, median, $75^{th}$ quantile and maximum value of the

813    variable. Colored bar charts represent the proportion of occurrence reported by trap

814    episodes. Colored box plots represent the median and interquartile range of the trap

815    rate amongst traps where the vector occurred.

816

817    **Supplementary Figure S4. Comparison of trap locations by longitudinal**

818    **training dataset and external no abundance testing dataset.**

819

820    **Supplementary Figure S5. Comparison of five datasets used in the study.**

821

822   **Supplementary Figure S6. Temporal variation in model predictions in**

823   **abundance of *Aedes aegypti* (A) and *Aedes albopictus* (B).** Points are the

824   median difference between predicted and observed abundance of *Aedes aegypti*

825   and *Ae. albopictus* from the main analysis. Intervals are the 2.5% and 97.5%

826   quantile of difference between predicted and observed abundance of the two *Aedes*

827   species. Histograms are the monthly average of observed trap rates.

828

829   **Supplementary Figure S7. Weekly predictions of occurrence of *Aedes aegypti***

830   **and *Aedes albopictus* from no abundance model in Florida.**

831

832   **Supplementary Figure S8. Geographic distribution of mosquito trap types in**

833   **the longitudinal training dataset.**

834
835   **Supplementary Figure S9. Correlation between predicted trap rate for *Aedes***

836   ***aegypti* using longitudinal data with and without data from Miami-Dade.**

837

838   **Figure S10. Maps on predicted abundance of *Aedes aegypti* (red) and *Aedes***

839   ***albopictus* (blue) in Florida, 2018.** Predictions are derived from "no abundance

840   model".

841

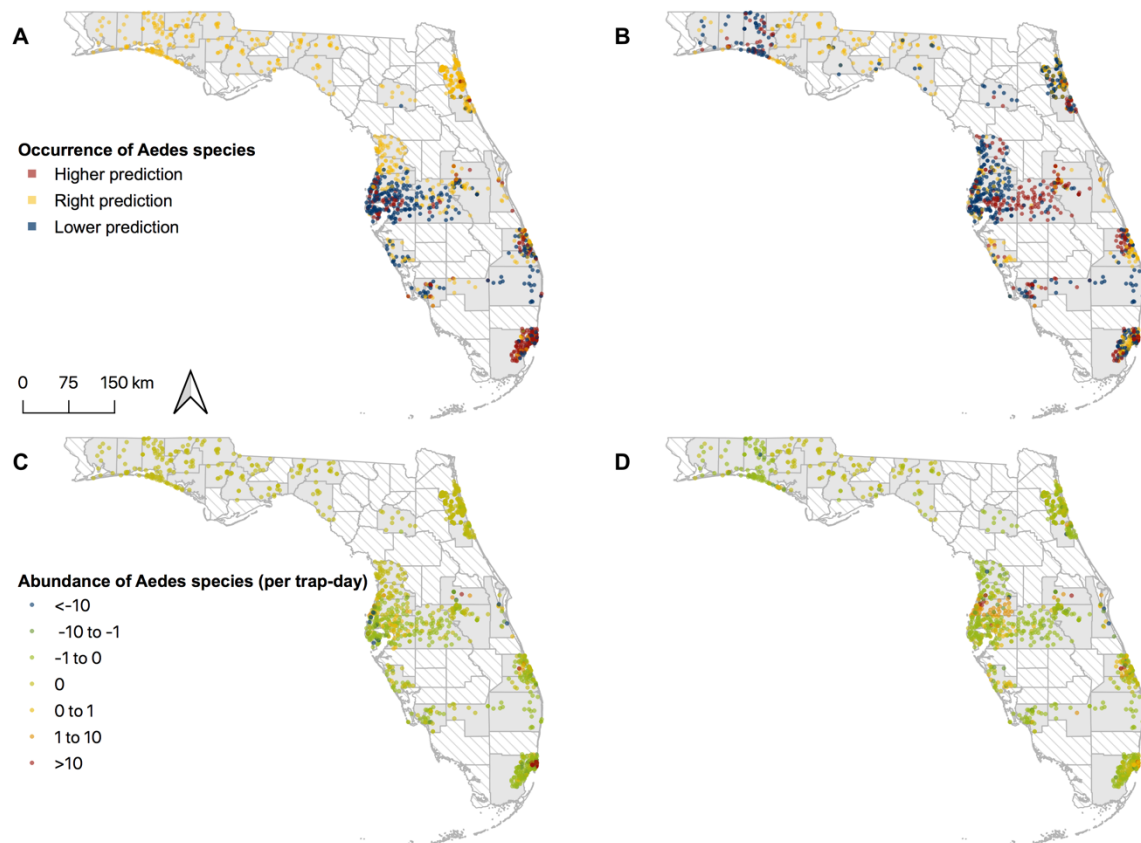**Figure 1**
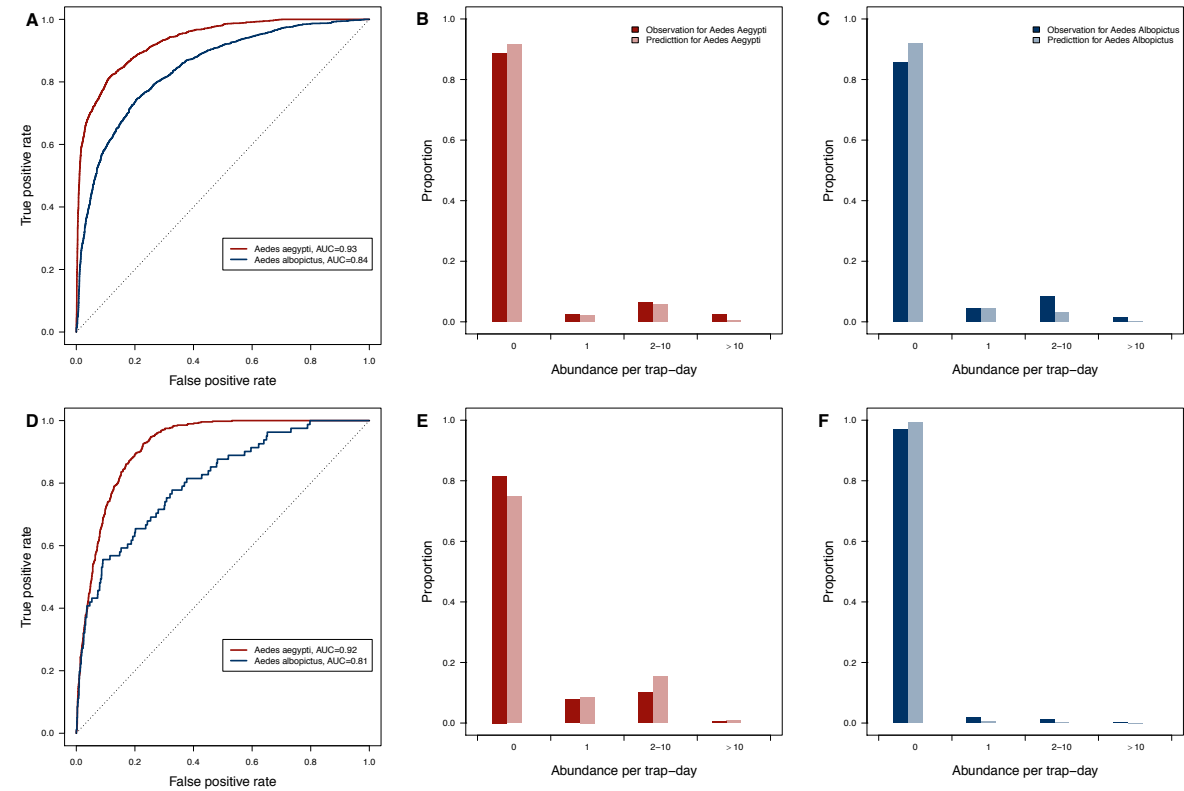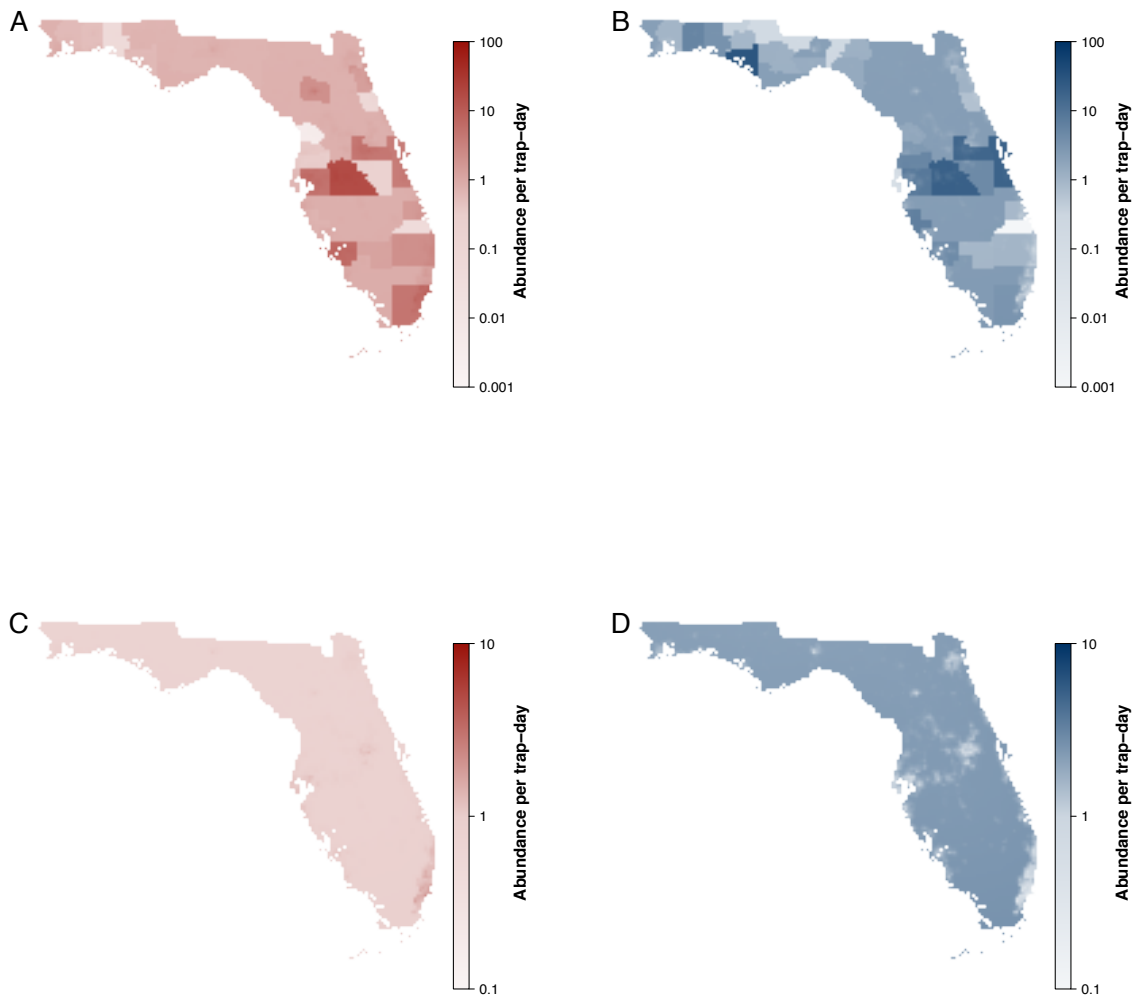
846  **Figure 2**



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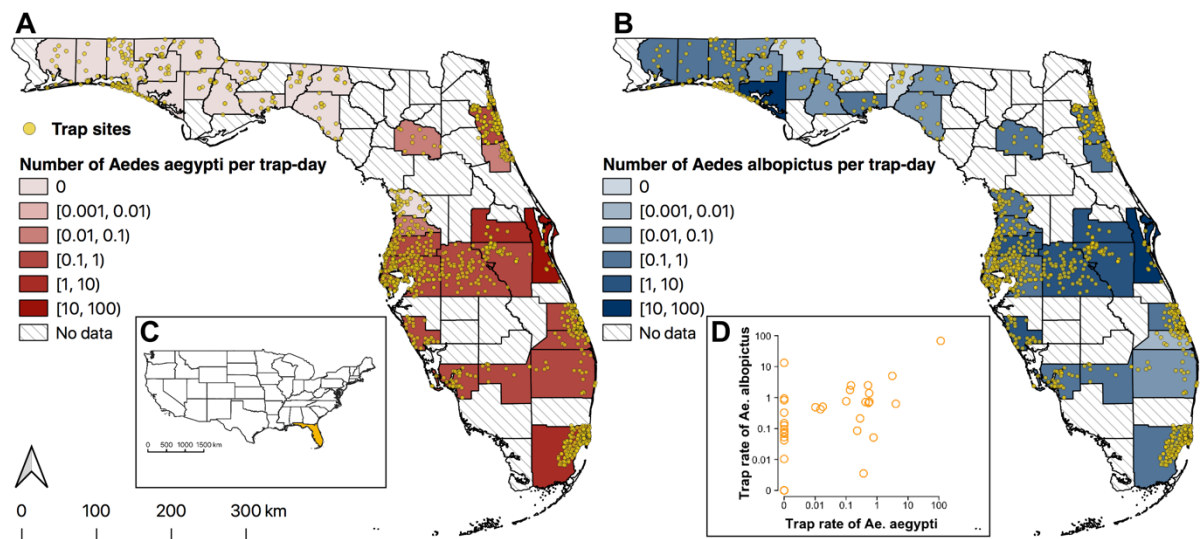
**Figure 3**

**Figure 4**

856 **Supplement Table S1.** Odds ratio (OR) and incidence rate ratio (IRR) estimate from

857 mixed-effects zero-inflated negative binomial analysis of covariates of *Aedes* trap

858 rates in Florida using data from NOAA, from 2004 to 2018.

| Variables | Aedes aegypti | | Aedes albopictus | |
|---|---|---|---|---|
| | OR (95% CrI†) | IRR (95% CrI†) | OR (95% CrI†) | IRR (95% CrI†) |
| **Previous *Ae. aegypti* abundance/presence** | | | | |
| Trap rate in week *t-1* | 2.44 (2.18, 2.74)* | 1.03 (1.02, 1.03)* | 1.22 (1.11, 1.35)* | 1.00 (1.00, 1.01) |
| Trap rate in week *t-2* | 2.42 (2.16, 2.71)* | 1.03 (1.03, 1.03)* | 1.43 (1.29, 1.58)* | 1.00 (0.99, 1.00) |
| Trap rate in week *t-3* | 1.81 (1.61, 2.03)* | 1.02 (1.01, 1.02)* | 1.05 (0.95, 1.16) | 1.00 (1.00, 1.01) |
| **Previous *Ae. albopictus* abundance/presence** | | | | |
| Trap rate in week *t-1* | 1.30 (1.16, 1.46)* | 0.99 (0.99, 1.00)* | 2.51 (2.35, 2.68)* | 1.02 (1.02, 1.03)* |
| Trap rate in week *t-2* | 1.46 (1.30, 1.64)* | 0.99 (0.99, 1.00)* | 2.23 (2.08, 2.38)* | 1.02 (1.01, 1.02)* |
| Trap rate in week *t-3* | 1.28 (1.14, 1.43)* | 0.99 (0.99, 1.00)* | 1.70 (1.59, 1.82)* | 1.02 (1.01, 1.02)* |
| **Human population density ($100/km^2$)** | 1.05 (1.03, 1.07)* | 1.01 (0.99, 1.02) | 0.95 (0.94, 0.97)* | 0.98 (0.97, 1.00)* |
| **Meteorology** | | | | |
| Average wind speed ($m/s$) | 0.98 (0.95, 1.00)* | 0.97 (0.96, 0.98)* | 0.97 (0.96, 0.98)* | 0.96 (0.95, 0.97)* |
| Minimum temperature (℃) | 1.01 (1.00, 1.02) | 1.11 (1.10, 1.11)* | 1.07 (1.06, 1.07)* | 1.08 (1.07, 1.08)* |
| Maximum temperature (℃) | 1.00 (0.96, 1.03) | 1.08 (1.06, 1.11)* | 1.09 (1.06, 1.11)* | 1.06 (1.04, 1.08)* |
| Precipitation ($mm$) | 0.85 (0.69, 1.05) | 1.42 (1.26, 1.59)* | 1.05 (0.94, 1.19) | 1.09 (0.99, 1.19) |

42

**Trap type**

| | | | | |
|---|---|---|---|---|
| BG sentinel | Ref. | Ref. | Ref. | Ref. |
| Light trap | 0.00 (0.00, 0.01)* | 0.40 (0.31, 0.52)* | 0.78 (0.60, 1.01) | 0.30 (0.24, 0.37)* |
| Other | 0.01 (0.00, 0.02)* | 0.20 (0.14, 0.29)* | 1.76 (1.28, 2.43)* | 0.26 (0.20, 0.33)* |

**Random effects**

| | | | | |
|---|---|---|---|---|
| Site | 1.32 | 1.66 | 1.38 | 0.90 |
| County | 12.24 | 2.82 | 6.57 | 1.63 |
| **Dispersion parameter** | -- | 1.45 (1.41, 1.50) | -- | 1.13 (1.10, 1.17) |

859    * $P < 0.05$. [†] Credible interval

860

861 **Supplement Table S2.** Odds ratio (OR) and incidence rate ratio (IRR) estimate from

862 mixed-effects zero-inflated negative binomial analysis of covariates of *Aedes aetypti*

863 and *Aedes albopictus* collected from BG traps.

| Variables | *Aedes aegypti* | | *Aedes albopictus* | |
|---|---|---|---|---|
| | OR (95% CrI†) | IRR (95% CrI†) | OR (95% CrI†) | IRR (95% CrI†) |
| **Previous *Ae. aegypti* abundance/presence** | | | | |
| Trap rate in week *t-1* | 5.16 (2.45, 10.87)* | 1.04 (1.03, 1.04)* | 0.99 (0.59, 1.67) | 1.00 (0.99, 1.02) |
| Trap rate in week *t-2* | 6.61 (3.48, 12.54)* | 1.02 (1.02, 1.03)* | 1.10 (0.64, 1.89) | 1.01 (0.99, 1.03) |
| Trap rate in week *t-3* | 8.58 (4.13, 17.85)* | 1.02 (1.01, 1.02)* | 0.65 (0.40, 1.08) | 1.00 (0.98, 1.02) |
| **Previous *Ae. albopictus* abundance/presence** | | | | |
| Trap rate in week *t-1* | 0.42 (0.22, 0.80)* | 1.02 (1.00, 1.03)* | 3.27 (1.98, 5.41)* | 1.06 (1.04, 1.07)* |
| Trap rate in week *t-2* | 0.96 (0.49, 1.90) | 0.99 (0.98, 1.01) | 1.12 (0.70, 1.79) | 1.06 (1.04, 1.07)* |
| Trap rate in week *t-3* | 0.78 (0.41, 1.50) | 0.99 (0.98, 1.01) | 3.00 (1.89, 4.77)* | 1.04 (1.02, 1.05)* |
| **Human population density ($100/km^2$)** | 1.12 (1.03, 1.23)* | 0.99 (0.98, 1.01) | 0.94 (0.90, 0.97)* | 0.99 (0.96, 1.02) |
| **Meteorology** | | | | |
| Average wind speed ($m/s$) | 1.16 (0.99, 1.35) | 0.97 (0.96, 0.99)* | 1.02 (0.92, 1.12) | 0.91 (0.87, 0.96)* |
| Minimum temperature (℃) | 1.02 (0.93, 1.13) | 1.12 (1.11, 1.13)* | 1.02 (0.97, 1.07) | 1.10 (1.07, 1.12)* |
| Maximum temperature (℃) | 1.25 (0.92, 1.70) | 1.07 (1.04, 1.10)* | 1.02 (0.86, 1.21) | 1.07 (0.99, 1.16) |

43

| | | | | |
|---|---|---|---|---|
| Relative humidity (%) | 0.31 (0.06, 1.53) | 1.58 (1.32, 1.89)* | 0.39 (0.18, 0.83)* | 1.27 (0.93, 1.73) |
| **Random effects** | | | | |
| Site | 0.30 | 0.60 | 0.87 | 0.57 |
| County | 2.36 | 0.81 | 4.30 | 1.19 |
| **Dispersion parameter** | -- | 1.35 (1.31, 1.40) | -- | 1.10 (0.98, 1.23) |

864

865    * P < 0.05. † Credible interval

866

**Supplementary Table S3.** Odds ratio (OR) and incidence rate ratio (IRR) estimate from mixed-effects zero-inflated negative binomial analysis of covariates of *Aedes aegypti* after removing data from Miami-Dade county.

| Variables | *Aedes aegypti* | |
|---|---|---|
| | OR (95% CrI[†]) | IRR (95% CrI[†]) |
| **Previous *Ae. Aegypti* abundance** | | |
| Trap rate of *Ae. aegypti* in week t-1 | 2.79 (2.41, 3.23)* | 1.03 (1.03, 1.04)* |
| Trap rate of *Ae. aegypti* in week t-2 | 2.26 (1.95, 2.61)* | 1.03 (1.03, 1.04)* |
| Trap rate of *Ae. aegypti* in week t-3 | 2.12 (1.83, 2.46)* | 1.02 (1.01, 1.03)* |
| **Previous *Ae. Albopictus* abundance** | | |
| Trap rate of *Ae. albopictus* in week t-1 | 1.45 (1.27, 1.66)* | 1.00 (0.99, 1.00) |
| Trap rate of *Ae. albopictus* in week t-2 | 1.48 (1.29, 1.70)* | 0.99 (0.98, 1.00)*† |
| Trap rate of *Ae. albopictus* in week t-3 | 1.41 (1.23, 1.62)* | 1.00 (0.99, 1.00) |
| **Human population density (100/$km^2$)** | 1.12 (1.09, 1.16)* | 1.08 (1.04, 1.12)* |
| **Meteorology** | | |
| Average wind speed ($m/s$) | 1.03 (0.99, 1.08) | 0.90 (0.88, 0.93)* |
| Minimum temperature (℃) | 1.03 (1.01, 1.04)* | 1.09 (1.08, 1.10)* |
| Maximum temperature (℃) | 1.02 (0.92, 1.13) | 1.03 (0.96, 1.10) |
| Relative humidity ($mm$) | 1.00 (0.98, 1.01) | 1.01 (1.00, 1.02)*† |
| **Random effects** | | |
| Site | 1.03 | 2.28 |
| County | 10.90 | 3.39 |
| **Dispersion parameter** | -- | 1.89 (1.78, 2.00) |

* P < 0.05. † Credible interval. † The values with three effective digits for these estimations are: 0.991 (0.984, 0.998) and 1.013 (1.003, 1.023).

45

874 **Supplementary Table S4.** Summary of other trap types included in the longitudinal

875 training dataset.

| Trap types | Number of records |
|---|---|
| **BG sentinel trap** | 9,518 (7.2%) |
| **Light trap** | 107,571 (81.4%) |
| CDC light traps | 95,554 (88.8%) |
| New Jersey light traps | 8,451 (7.9%) |
| Non-specific light traps | 3,566 (3.3%) |
| **Other trap types** | 14,999 (11.4%) |
| Mosquito magnet | 3,545 (23.6%) |
| Suction trap | 3,372 (22.5%) |
| Propane | 2,676 (17.8%) |
| ABC | 1,920 (12.8%) |
| Gravid trap | 1,827 (12.2%) |
| Exit | 1,178 (7.9%) |
| Route | 268 (1.8%) |
| Unknown | 139 (0.9%) |
| Fay prince | 64 (0.4%) |
| Wilton trap | 10 (0.1%) |

876

877

878 **Supplementary Table S5.** Surveillance data by county

| County | Full | ZINB | Spatial Training | Temporal Training | No Abundance Testing |
|---|---|---|---|---|---|
| Hillsborough | 24854 (14.0%) | 16475 (12.5%) | 14861 (12.5%) | 16475 (12.7%) | 8379 (18.4%) |
| Pinellas | 22335 (12.6%) | 20058 (15.2%) | 18607 (15.7%) | 19673 (15.2%) | 2277 (5.0%) |
| St. Johns | 21872 (12.3%) | 17751 (13.4%) | 15954 (13.4%) | 17751 (13.7%) | 4121 (9.1%) |
| Polk | 20751 (11.7%) | 15543 (11.8%) | 12528 (10.5%) | 15543 (12.0%) | 5208 (11.4%) |
| Dade | 18634 (10.5%) | 14980 (11.3%) | 14129 (11.9%) | 14158 (10.9%) | 3654 (8.0%) |
| Lee | 13812 (7.8%) | 8045 (6.1%) | 6613 (5.6%) | 8045 (6.2%) | 5767 (12.7%) |
| Citrus | 8471 (4.8%) | 6959 (5.3%) | 6695 (5.6%) | 6959 (5.4%) | 1512 (3.3%) |
| Walton | 8380 (4.7%) | 6186 (4.7%) | 5890 (5.0%) | 6106 (4.7%) | 2194 (4.8%) |
| Palm Beach | 7864 (4.4%) | 7008 (5.3%) | 6551 (5.5%) | 6912 (5.3%) | 856 (1.9%) |
| Pasco | 5722 (3.2%) | 3468 (2.6%) | 2922 (2.5%) | 3468 (2.7%) | 2254 (5.0%) |
| Osceola | 4522 (2.5%) | 2203 (1.7%) | 1989 (1.7%) | 2203 (1.7%) | 2319 (5.1%) |
| St. Lucie | 3717 (2.1%) | 2746 (2.1%) | 2527 (2.1%) | 2493 (1.9%) | 971 (2.1%) |
| Flagler | 3715 (2.1%) | 3150 (2.4%) | 2880 (2.4%) | 3118 (2.4%) | 565 (1.2%) |
| Martin | 2660 (1.5%) | 2561 (1.9%) | 2453 (2.1%) | 2350 (1.8%) | 99 (0.2%) |
| Alachua | 2015 (1.1%) | 1538 (1.2%) | 1194 (1.0%) | 1538 (1.2%) | 477 (1.0%) |
| Hernando | 1868 (1.1%) | 1526 (1.2%) | 1299 (1.1%) | 1526 (1.2%) | 342 (0.8%) |
| Hendry | 1052 (0.6%) | 437 (0.3%) | 337 (0.3%) | 437 (0.3%) | 615 (1.4%) |
| Sarasota | 1004 (0.6%) | 268 (0.2%) | 249 (0.2%) | 268 (0.2%) | 736 (1.6%) |
| Bay | 933 (0.5%) | 137 (0.1%) | 105 (0.1%) | 137 (0.1%) | 796 (1.7%) |
| Orange | 724 (0.4%) | 35 (0%) | 35 (0%) | 35 (0%) | 689 (1.5%) |
| Okaloosa | 324 (0.2%) | 216 (0.2%) | 216 (0.2%) | 132 (0.1%) | 108 (0.2%) |
| Santa Rosa | 324 (0.2%) | 168 (0.1%) | 168 (0.1%) | 108 (0.1%) | 156 (0.3%) |
| Brevard | 176 (0.1%) | 30 (0%) | 25 (0%) | 30 (0%) | 146 (0.3%) |
| Holmes | 156 (0.1%) | 84 (0.1%) | 84 (0.1%) | 0 (0%) | 72 (0.2%) |
| Liberty | 150 (0.1%) | 84 (0.1%) | 77 (0.1%) | 0 (0%) | 66 (0.1%) |
| Madison | 149 (0.1%) | 44 (0%) | 40 (0%) | 0 (0%) | 105 (0.2%) |
| Bradford | 137 (0.1%) | 0 (0%) | 0 (0%) | 0 (0%) | 137 (0.3%) |
| Wakulla | 132 (0.1%) | 82 (0.1%) | 82 (0.1%) | 0 (0%) | 50 (0.1%) |
| Indian River | 130 (0.1%) | 0 (0%) | 0 (0%) | 0 (0%) | 130 (0.3%) |
| Washington | 130 (0.1%) | 38 (0%) | 26 (0%) | 0 (0%) | 92 (0.2%) |
| Taylor | 120 (0.1%) | 84 (0.1%) | 84 (0.1%) | 0 (0%) | 36 (0.1%) |
| Gadsden | 108 (0.1%) | 48 (0%) | 44 (0%) | 0 (0%) | 60 (0.1%) |
| Jackson | 108 (0.1%) | 56 (0%) | 53 (0%) | 0 (0%) | 52 (0.1%) |
| Jefferson | 108 (0.1%) | 41 (0%) | 33 (0%) | 0 (0%) | 67 (0.1%) |
| Calhoun | 99 (0.1%) | 39 (0%) | 31 (0%) | 0 (0%) | 60 (0.1%) |
| Collier | 91 (0.1%) | 0 (0%) | 0 (0%) | 0 (0%) | 91 (0.2%) |
| Gulf | 65 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 65 (0.1%) |

| | | | | | |
|---|---|---|---|---|---|
| Charlotte | 57 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 57 (0.1%) |
| Escambia | 40 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 40 (0.1%) |
| Okeechobee | 31 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 31 (0.1%) |
| Union | 15 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 15 (0%) |
| Leon | 13 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 13 (0%) |
| Baker | 10 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 10 (0%) |
| Dixie | 10 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 10 (0%) |
| Gilchrist | 10 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 10 (0%) |
| Marion | 10 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 10 (0%) |
| Suwannee | 10 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 10 (0%) |
| Nassau | 5 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 5 (0%) |
| Total | 177623 | 132088 | 118781 | 129465 | 45535 |

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880 **Figure S1**



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883 **Figure S2**
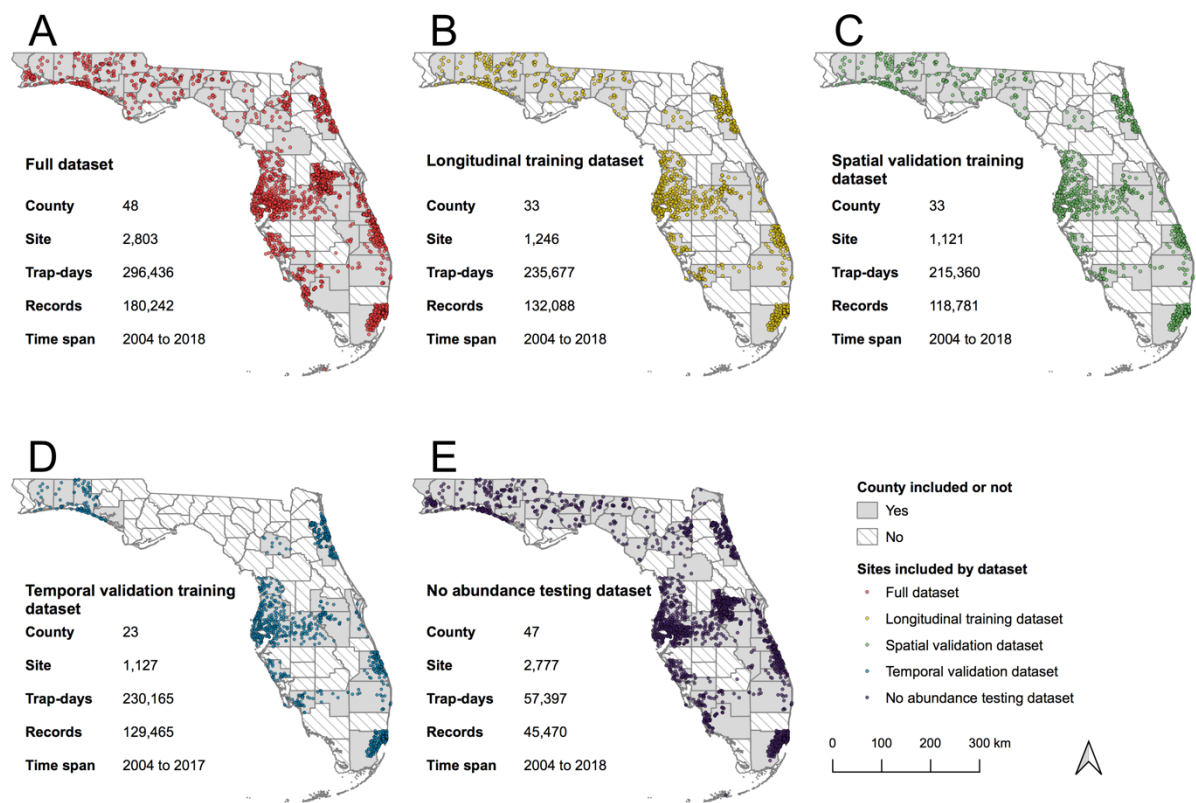
A

**Week of Apr 05, 2004**

- Presence of Aedes aegypti
- Absence of Aedes aegypti

B

**Week of Apr 05, 2004**

- Presence of Aedes albopictus
- Absence of Aedes albopictus

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885 **Figure S3**



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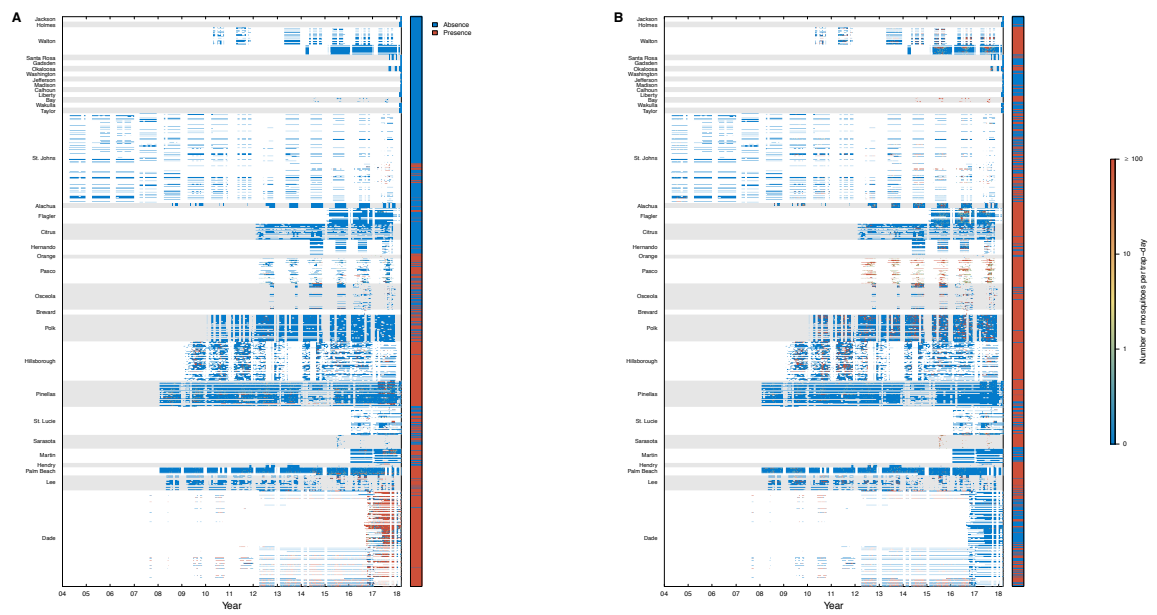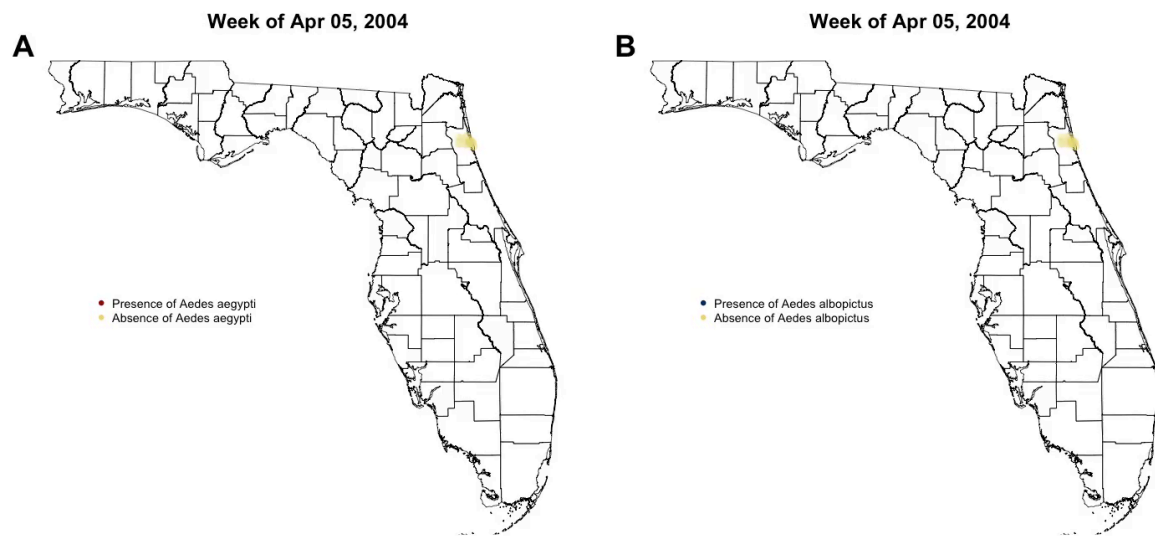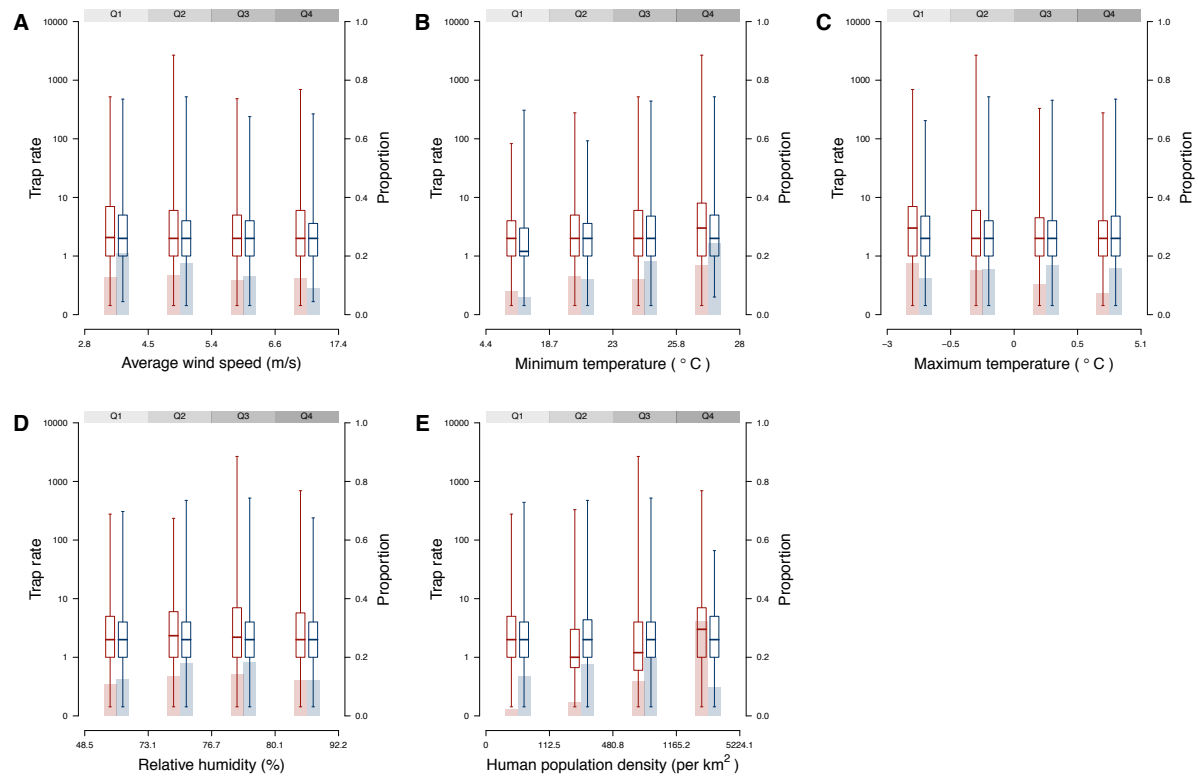
888    **Figure S4**
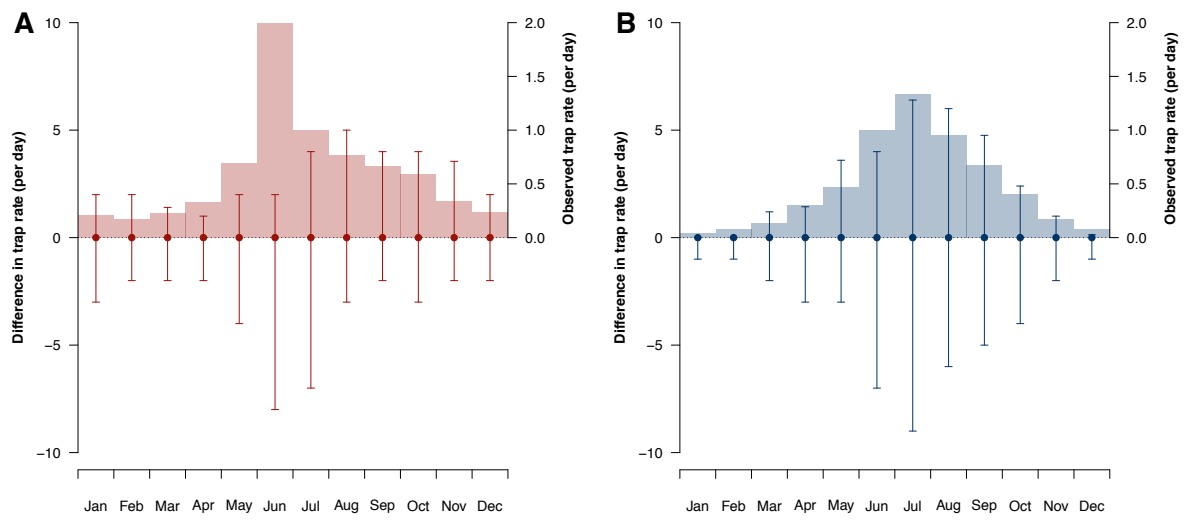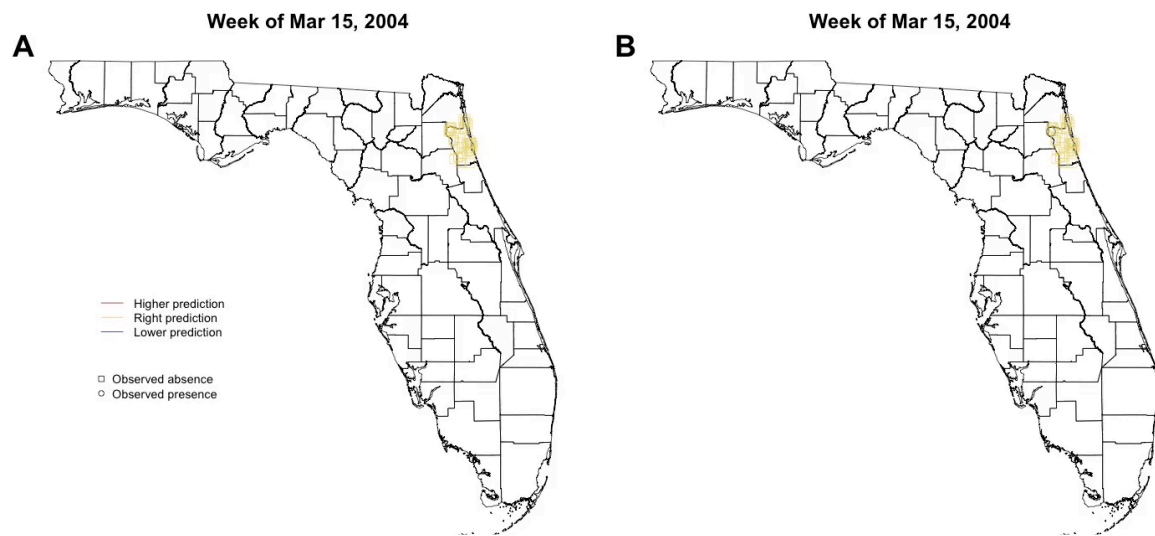
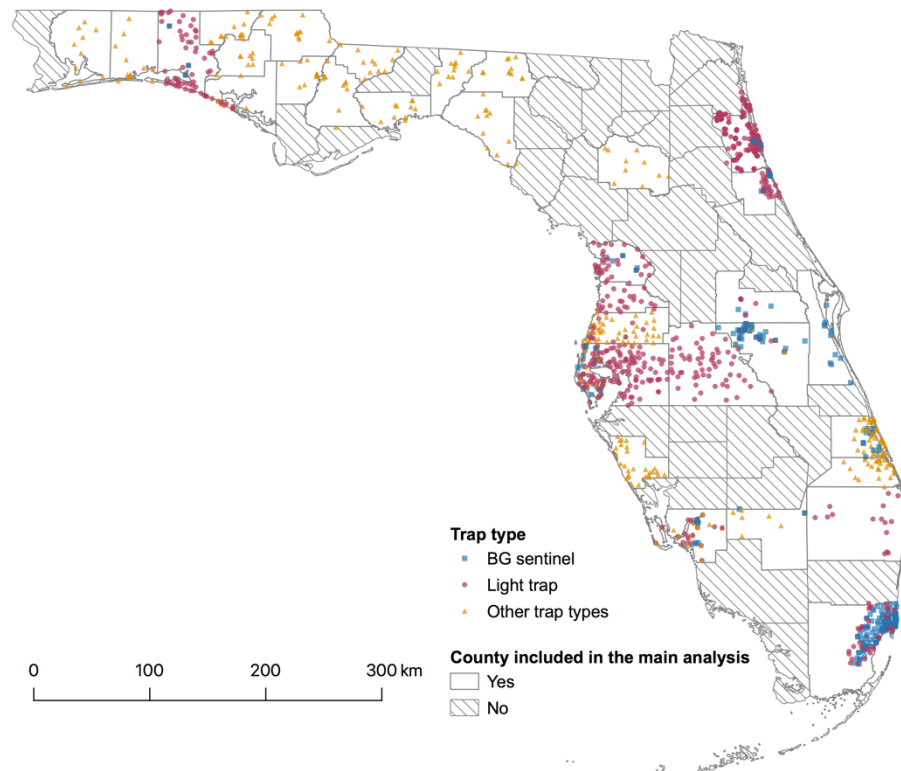

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**Figure S5**

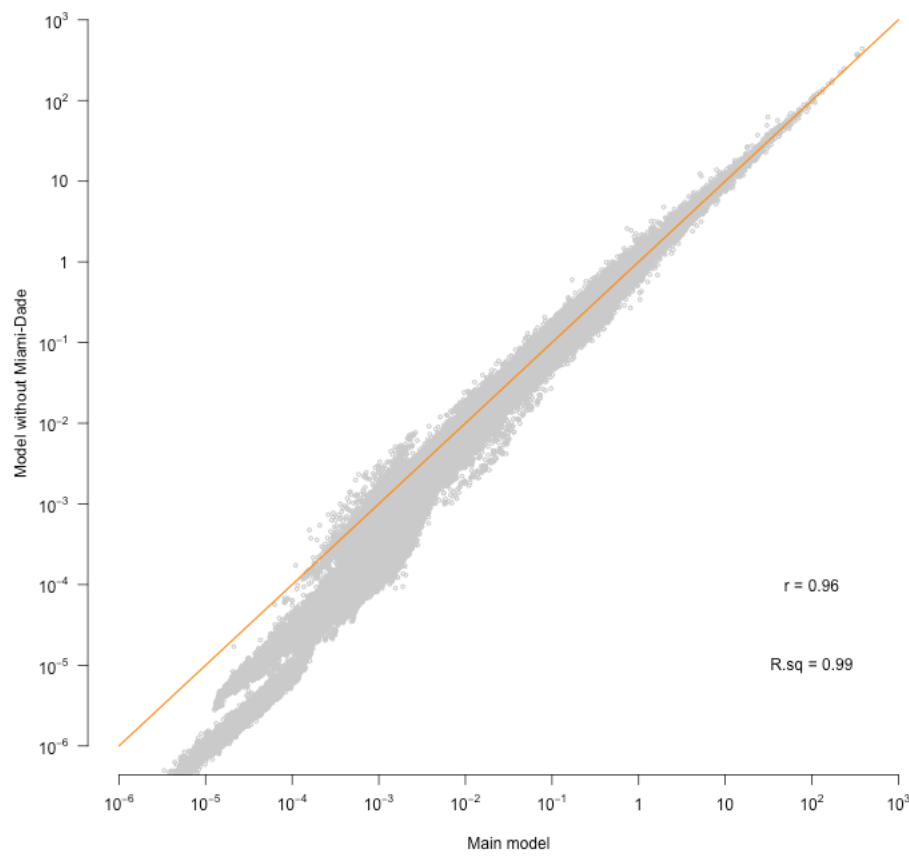**Figure S6**



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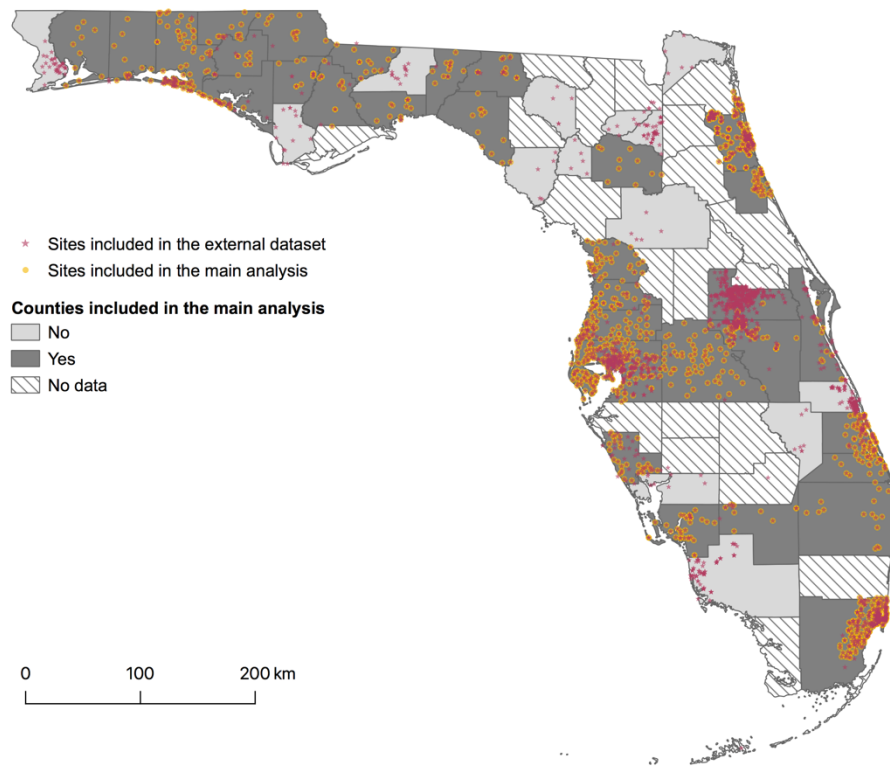
897 **Figure S7**



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899 **Figure S8**



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902 **Figure S9**



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905 **Figure S10**

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