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Lfinkfing mathematficafl modefls and trap data to finfer the proflfiferatfion, abundance, and controfl of *Aedes aegyptfi*

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ABSTRACT

Aedes aegyptfi fis one of the most domfinant mosqufito specfies fin the urban areas of Mfiamfi-Dade County, Fflorfida, and fis responsfibfle for the flocafl arbovfirus transmfissfions. Sfince August 2016, mosqufito traps have been pflaced throughout the county to fimprove survefiflflance and gufide mosqufito controfl and arbovfirus outbreak response. In thfis paper, we deveflop a determfinfistfic mosqufito popuflatfion modefl, estfimate modefl parameters by usfing flocafl entomoflogficafl and temperature data, and use the modefl to caflfibrate the mosqufito trap data from 2017 to 2019. We further use the modefl to compare the *Ae. aegyptfi* popuflatfion and evafluate the fimpact of rafinfaflfl fintensfity fin dfifferent urban bufiflt envfironments. Our resuflts show that rafinfaflfl affects the breedfing sfites and the abundance of *Ae. aegyptfi* more sfignfifficantfly fin tourfist areas than fin resfidentfiafl pflaces. In addfitfion, we appfly the modefl to quantfitatfivefly assess the effectfiveness of vector controfl strategfies fin Mfiamfi-Dade County.

1. Introductfion

Aedes aegyptfi fis the prfimary vector responsfibfle for the transmfissfion of severafl arbovfiruses, fincfludfing dengue fever, chfikungunya, yeflflow fever, and Zfika fever. It fis commonfly found fin tropficafl and subtropficafl areas and fis one of the most wfidespread mosqufito specfies. Urbanfizatfion and human movement are hfighfly reflated to the presence and dfistrfibutfion of *Ae. aegyptfi* mosqufitoes whfich aflmost excflusfivefly feed on humans (Ponflawat and Harrfington, 2005; Wfiflke et afl., 2021a) - makfing them extremefly threatenfing fin terms of spreadfing emergfing and re-emergfing vector-borne dfiseases. Dengue, chfikungunya, and Zfika have been fintroduced finto Fflorfida, caused flocafl outbreaks (dengue fin 2010 and 2020, chfikungunya fin 2014, Zfika fin 2016), and posed a major pubflfic heaflth probflem there sfince *Ae. aegyptfi* mosqufitoes are wfidefly dfistrfibuted throughout Fflorfida. *Ae. aegyptfi* mosqufitoes prefer artfifficfiafl aquatfic habfitats such as fflower vases, tfires, barrefls, cans, and bottfles, posfing a sfignfifficant chaflflenge agafinst most mosqufito controfl programs. Mosqufito reflatfive abundance fis usuaflfly monfitored vfia efither mechanficafl traps that attract femafle aduflts seekfing hosts or ovfitraps that attract femafle aduflts to flay thefir eggs. Whenever vector controfl finterventfions are carrfied out, mosqufito trap data coflflected before and after the finterventfions can serve as the prfimary resource for evafluatfion and assessment.

Sfince August 2016 durfing the Zfika outbreak, the Mfiamfi-Dade County Mosqufito Controfl survefiflflance network have pflaced BG-Sentfinefl traps (BfioGents Corporatfion, Regensburg, Germany) to monfitor the flocafl aduflt mosqufito popuflatfion. BG-Sentfinefl traps that are enhanced wfith CO_2 refleased from dry fice fin a smaflfl coofler are the gofld standard for coflflectfing severafl mosqufito specfies fincfludfing *Ae. aegyptfi* (Wfiflke et afl., 2019a). The survefiflflance network covered the totaflfity of Mfiamfi-Dade County, wfith partficuflar attentfion gfiven to the areas affected by the 2016 Zfika outbreak and hfigh human mobfiflfity: Mfiamfi Beach, Homestead, Wynwood and Brfickeflfl (Wfiflke et afl., 2019c). Data coflflected from mosqufito traps represent a random sampflfing from the actuafl mosqufito popuflatfion, and have served as the major findficator for the evafluatfion of vector controfl effficacy for years (Pruszynskfi et afl., 2017; Wfiflflfiams et afl., 2022). However, due to varfious unexpected reasons such as floose or torn

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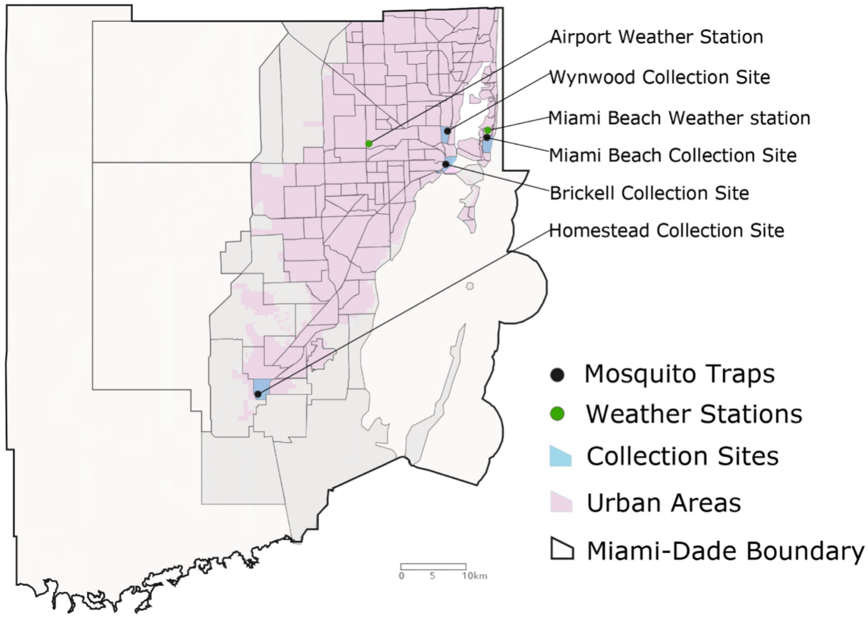


Ffig. 1. Map of Mfiamfi-Dade County.

catch bags, flocked gates, trap finvasfion by flfizards, a certafin number of traps occasfionaflfly maflfunctfioned, resufltfing fin mfissfing data from many observatfionafl days and traps (Stoddard, 2018). In addfitfion, sometfimes the functfionfing traps aflso fafifl to detect mosqufitoes as they are not around due to envfironmentafl condfitfions (too cofld, too hot, or too wfindy), not attracted by the traps, or thefir numbers are flow for some unknown reason. As a resuflt, over a three-year perfiod, the traps flocated fin Mfiamfi Beach, Homestead, Wynwood, and Brfickeflfl provfide respectfivefly 86, 109, 120, and 101 data pofints. Further, most of the data were not sampfled on the same day, whfich makes fit chaflflengfing to compare trap data from dfifferent flocatfions vfia sfimpfle statfistficafl methods. Thus the random sampflfing data may not dfirectfly provfide credfibfle estfimatfions of the mosqufito popuflatfions, whfich coufld pose dfiffficufltfies fin the assessment of vector controfl strategfies. Mathematficafl modefls fincorporated wfith mechanfisms of popuflatfion dynamfics, when flfinked wfith trap data, are effectfive toofls fin understandfing the underflyfing dynamfics of the mosqufito popuflatfion and assessfing the potentfiafl effectfiveness of controfl finterventfions.

Mosqufitoes are ectothermfic, meanfing that thefir reproductfion, deveflopment, feedfing, and survfivafl rates refly on externafl sources of heat. The entomoflogficafl parameters regardfing mosqufitoes' flfife cycfle under dfifferent temperatures have been weflfl studfied and documented fin many experfimentafl papers (Deflatte et afl., 2009; Farnesfi et afl., 2009; Rueda et afl., 1990; Yang et afl., 2009). *Ae. aegyptfi* fis known as "contafiner-breedfing", and femafle mosqufitoes prefer to flay eggs fin water-fiflfled contafiners (Wfiflke et afl., 2019b; 2020). Thus the abundance of *Ae. aegyptfi* may be finfluenced by rafinfaflfl, but fits actuafl contrfibutfion fis stfiflfl uncflear. Ordfinary dfifferentfiafl equatfion (ODE) modefls have been one of other sfignfifficant approaches to sfimuflate mosqufito popuflatfion dynamfics, wfith the weather data fincorporated as tfime-dependent parameters fin the modefl systems. Modefls wfith human-mosqufito finteractfions have been wfidefly appflfied to expflafin the patterns of vector-borne dfisease outbreaks and estfimate the potentfiafl future rfisks where the sfimuflatfions were matched wfith human case data (Hfladfish et afl., 2018; Meteflmann et afl., 2019; 2021; Poflettfi et afl., 2011; Robert et afl., 2016; Ye et afl., 2007) or together wfith mosqufito trap data (Cafldweflfl et afl., 2021; Leach et afl., 2020; Lfi et afl., 2019; Marfinfi et afl., 2017; Ofidtman et afl., 2021; Petrone et afl., 2021; Yfi et afl., 2019). Specfifficaflfly, to finfer mosqufito popuflatfion fin the ffiefld, dfifferentfiafl equatfions modefls have been devefloped wfith varfiabfles representfing the popuflatfion fin each stage of the mosqufito's flfife cycfle. Some modefls have been empfloyed to caflfibrate the entomoflogficafl parameters and the carryfing capacfity wfith cflfimate data (Ewfing et afl., 2016; Ezanno et afl., 2015; Sfimoy et afl., 2015) and compare the modefl sfimuflatfion wfith the seasonafl trends findficated by trap data (Vafidya et afl., 2014) or ovfitrap data (Tran et afl., 2013; 2020). Other modefls further fincflude severafl uncertafin factors subject to the naturafl envfironment, such as the finfluence of the fintensfity of rafinfaflfl on carryfing capacfity, the hazard rfisk of death fin the wfifld, finter-specfiffic competfitfion, and the effficfiency of traps or ovfitraps (Ergufler et afl., 2016; Ewfing et afl., 2019; Lana et afl., 2014; 2018; Marfinfi et afl., 2016; Nance et afl., 2018; Vafldez et afl., 2018; Whfite et afl., 2011). Such assumptfions resuflt fin unknown modefl parameters that need to be estfimated vfia data ffittfing. The fissue of parameter unfidentfiffiabfiflfity exfists fin most studfies that finvoflve data ffittfing, and thfis probflem has been addressed fin very few studfies (Lana et afl., 2014; 2018). On the basfis of our search, onfly a few studfies have finvestfigated vector controfl strategfies vfia sfimuflatfions. Onfly one study provfides resuflts based on ffittfing to trap data (Cafiflfly et afl., 2012; Dumont and Chfirofleu, 2010; Whfite et afl., 2011).

In thfis paper, we propose a determfinfistfic modefl to finvestfigate the growth, abundance, and controfl of *Ae. aegyptfi* mosqufitoes fin Mfiamfi-Dade County vfia the caflfibratfion of the *Ae. aegyptfi* trap data coflflected from January 2017 to December 2019 - whfich fis a perfiod not affected by the outbreaks of Zfika fin 2016 or COVID-19 after 2020. More specfifficaflfly, we afim to (*fi*) determfine the modefl parameters that are fidentfiffiabfle and justfify our ffindfings vfia ffittfing experfiments; (*fifi*) finvestfigate the necessfity of fincorporatfing temperature and precfipfitatfion data fin the sfimuflatfion of the flocafl mosqufito popuflatfion dynamfics by comparfing the goodness of ffittfing; (*fififi*) utfiflfize the modefl to compare mosqufito popuflatfion and envfironmentafl dfifferences among communfitfies; and (*fiv*) anaflyze the effectfiveness of usfing finsectficfides under afl possfibfle sfituatfions.

2. Materfial and Methods

2.1. Data

Mosqufito trap data. Each trap fis turned on to attract and coflflect mosqufitoes for precfisefly 24 hours on fits survefiflflance day. Coflflected mosqufitoes are fidentfiffied to specfies. We therefore obtafin the sampflfing of femafle *Ae. aegyptfi* captured fin every sfingfle trap on each survefiflflance day. The trap attracts femafle mosqufitoes by mfimfickfing a host. Both mafles

Table 1
Goodness of Ffittfing

Quantfity	Reduced Modefl	7-day Modefl	21-day Modefl	42-day Modefl
Mfiamfi Beach trap (86 data pofints)				
LOO	-342.20	-330.83	-328.84	-327.32
SE	41.72	39.54	38.80	38.36
Coverage	73	81	82	83
Homestead trap (109 data pofints)				
LOO	-671.17	-672.90	-676.05	-673.14
SE	127.48	130.93	130.62	128.59
Coverage	76	98	96	77
Wynwood trap (120 data pofints)				
LOO	-1029.69	-1011.86	-1014.99	-1020.23
SE	143.60	140.75	143.40	146.45
Coverage	56	91	94	90
Brfickell trap (101 data pofints)				
LOO	-428.55	-424.19	-428.11	-430.18
SE	82.31	78.36	79.46	81.03
Coverage	90	96	97	96

LOO: fleave-one-out cross-vaflfidatfion. SE: standard error. Coverage: number of pofints covered fin the 95% predfictfion fintervafl.

and femafles are coflflected by the traps but mafles are accfidentafl catches sfince they were probabfly tryfing to mate wfith the femafles. Note that femafle *Ae. aegyptfi* onfly ffly 100□500 meters from thefir breedfing sfites, thus the trap count for each survefiflflance day can be regarded as a random sampflfing of the *Ae. aegyptfi* popuflatfion fin the correspondfing communfity. In 2016 durfing the Zfika outbreak, Mfiamfi-Dade County enforced fintensfive vector controfl actfivfitfies, and the number of mosqufitoes rapfidfly decreased. Sfince earfly 2020, COVID-19 pandemfic has aflso brought fifnfluences on the frequency of outdoor actfivfitfies and the exposure to mosqufitoes, whfich coufld findfirectfly fimpact the *Ae. aegyptfi* popuflatfion that prfimarfifly feed on human. Therefore, we focus our anaflyses on the trap data coflflected from January 2017 to December 2019 to avofid the unexpected fifnfluences of the two recent dfisease outbreaks. We seflect three traps flocated fin Mfiamfi Beach, Wynwood, and Brfickeflfl, top-rated tourfist destfinatfions, thus possessfing the hfighest human mobfiflfity. In addfitfion, we seflect the trap flocated fin Homestead, a popuflated resfidentfiafl area away from downtown Mfiamfi whfich has a more dfiverse envfironment compared to the other three. Ffig. 1 fiflflustrates aflfl trap flocatfions and the nearby weather statfions.

Temperature and precfipfitatfion data. The dafifly average temperature and dafifly precfipfitatfion durfing the study perfiod were obtafined from the open-access database of the Natfionafl Oceanfic and Atmospherfic Admfinfistratfion (NOAA). We choose data from the weather statfion that fis geographficaflfly the cflosest to each trap flocatfion to represent the flocafl communfity weather: data from Mfiamfi Internatfionafl Afirport for traps fin Brfickeflfl, Wynwood, and Homestead; and data from Mfiamfi Beach statfion for the trap fin Mfiamfi Beach.

Thermal-response test data. We extract the entomoflogficafl parameters of *Ae. aegyptfi* under varfious temperatures from pubflfished experfiment data (Yang et afl., 2009). Specfifficaflfly, we coflflect the temperature-dependent data pofints on the average survfivafl tfime for the aquatfic phase, the average transfitfion tfime from the aquatfic stage to aduflt, the average survfivafl tfime for femafle mosqufitoes, and the average ovfiposfitfion rate (*fi.e.* the number of eggs flafid per mosqufito per day).

2.2. Baseflfine Model

We deveflop a determfinfistfic ODE modefl wfith tfime-dependent parameters to sfimuflate the *Ae. aegyptfi* popuflatfion fin each communfity. To fincorporate the fleast number of unknown parameters, we sfimpfly subdfivfide the mosqufito popuflatfion finto two cflasses: the fimmature mosqufito popuflatfion fin the aquatfic stage at tfime t ($J(t)$), and the aduflt femafle mosqufito popuflatfion at tfime t ($A(t)$). We onfly consfider aduflt femafle *Ae. aegyptfi* because onfly femafle mosqufitoes are seekfing for bflood meafls and coufld be attracted to the traps. The compartmentafl modefl fis presented fin Ffig. A1 and equatfions are gfiven as fofllows:

$$\begin{aligned} J'(t) &= b(t)\left(1 \quad \frac{J(t)}{K(t)}\right)A(t) \quad \mu_1(t)J(t) \quad d(t)J(t), \\ A'(t) &= \frac{1}{2}d(t)J(t) \quad \mu_2(t)A(t), \end{aligned} \tag{2.1}$$

where $b(t)$ represents the tfime-dependent ovfiposfitfion rate, $d(t)$ denotes the tfime-dependent deveflopment rate, $\mu_1(t)$ and $\mu_2(t)$ respectfivefly refer to the tfime-dependent death rates of fimmature and aduflt mosqufitoes. The fractfion 1/2 fin the second equatfion refers to our assumptfion that haflf of the fimmature popuflatfion wfiflfl deveflop finto aduflt femafle mosqufitoes. We assume that there fis a carryfing capacfity for the aquatfic stage popuflatfion, $K(t)$, whfich may depend on tfime.

2.3. Entomoflogfical Parameters

The entomoflogficafl parameters $b(t)$, $d(t)$, $\mu_1(t)$, and $\mu_2(t)$ are obtafined by composfing the tfime-dependent temperature functfion and the correspondfing temperature-dependent entomoflogficafl functfion. Let T denote the varfiabfle of temperature, we adopt the thermafl-response functfions as shown beflow (Mordecafi et afl., 2017).

$$\mu_1(T) = \frac{1}{c(T \quad T_0)(T_m \quad T)^{\frac{1}{2}}}, \tag{2.2}$$

$$\mu_2(T) = \frac{1}{c(T \quad T_0)(T_m \quad T)}, \tag{2.3}$$

$$b(T) = c(T \quad T_0)(T_m \quad T)^{\frac{1}{2}}, \tag{2.4}$$

where fin each functfion, T_0 and T_m are the mfinfimum and maxfimum temperature for the survfivafl of *Ae. aegyptfi* at the correspondfing stage, respectfivefly, wfith c befing a posfitfive rate constant.

$$d(T) = \frac{aT_K e^{b(1/298.15 \quad 1/T_K)}}{298.15(1 + e^{c(1/d \quad 1/T_K)})}, \tag{2.5}$$

where T_K fis the temperature fin Keflvfin scafle and a, b, c, d are posfitfive constants. Aflfl coeffficfients shown fin functfions (2.2)-(2.5) are ffitted to the thermafl-response test data (Yang et afl., 2009). The ffittfings are carrfied out by utfiflfizfing the method of Monte Carflo Markov Chafin (MCMC) vfia the software *Stan*. The ffitted coeffficfients for each functfion are summarfized fin Tabfle 2, and the ffittfing outcomes together wfith the experfimentafl data are pflotted fin Ffig. 2. In thfis way, we obtafin the entomoflogficafl parameter vaflues of *Ae. aegyptfi* under arbfitrary temperature.

To obtafin the tfime-dependent entomoflogficafl parameters fin modefl (2.1), we ffirst acqufire the dafifly temperature data T_i, wfith $i = 0, 1, 2, ..., N$ (N denotes the flast day of sfimuflatfion). By composfing the temperature-dependent functfions, we get the entomoflogficafl vaflues on each day, $\mu_1(T_i)$, $\mu_2(T_i)$, $b(T_i)$, $d(T_i)$ wfith $i = 0, 1, 2, ..., N$. Ffinaflfly, we ffit each dafifly entomoflogficafl data to trfigonometrfic functfions wfith a perfiod of 365 days to get the contfinuous tfime dependent vaflues: $\mu_1(t)$, $\mu_2(t)$, $b(t)$, $d(t)$. The tfime-dependent entomoflogficafl parameters are summarfized fin Tabfle 3.

2.4. Assumptfions on the Carryfing Capacfity

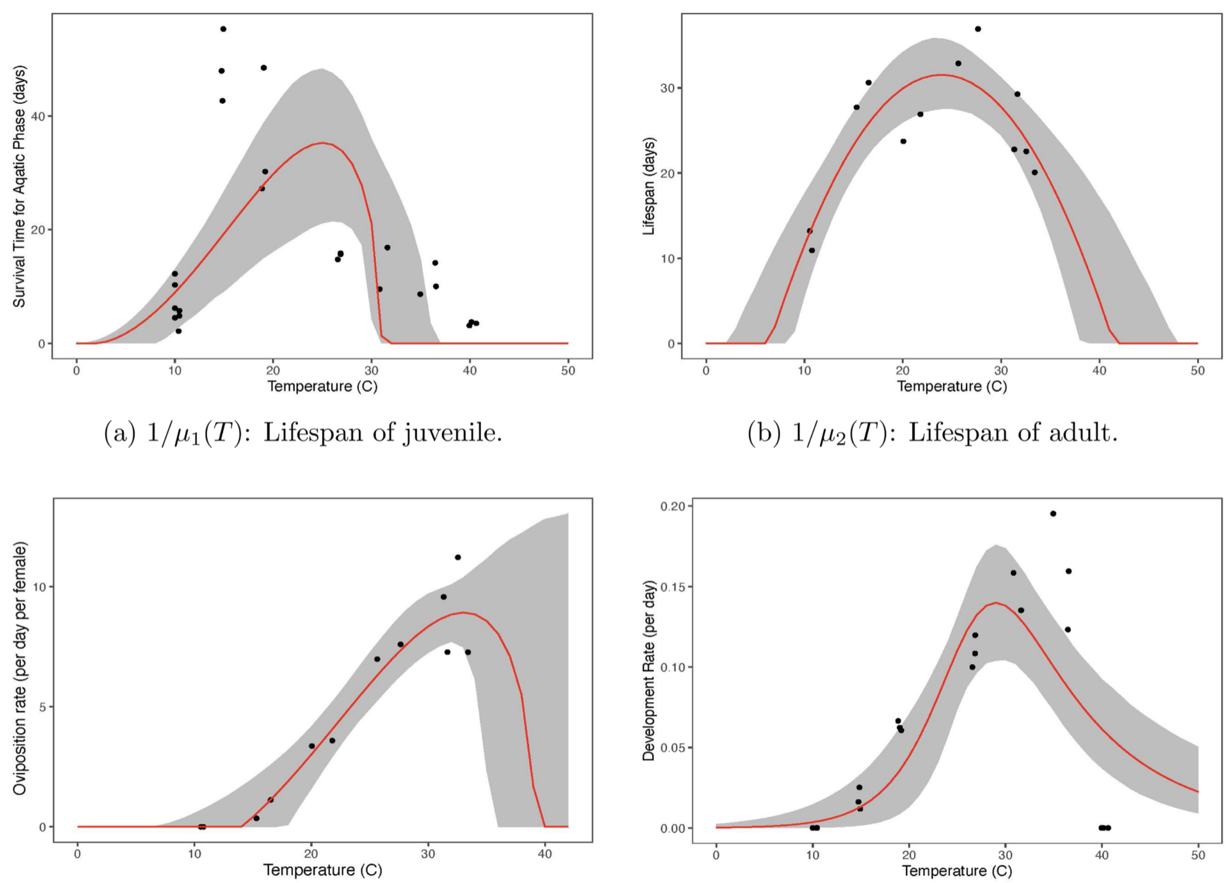
The carryfing capacfity for fimmature mosqufito popuflatfion coufld be dfirectfly fimpacted by the cumuflatfive rafinfaflfl fin the area. Water puddfles and water-ffiflfled contafiners are perfect resources for *Ae. aegyptfi* to flay eggs, so cumuflatfive rafinfaflfl may have a posfitfive fimpact on the carryfing capacfity. We formuflate

$$K(t) = K(1 + \alpha P_n(t)) \tag{2.6}$$

wfith K befing the baseflfine carryfing capacfity, and α befing the fimpact fintensfity of rafinfaflfl on carryfing capacfity. $P_n(t)$ fis an findex that measures the effect of cumuflatfive rafinfaflfl fin the past n days at tfime t, and fis

Table 2
Thermafl-response Functfions wfith Ffitted Coeffficfients

Varfiabfles	Functfions	Estfimates (medfian and credfibfle fintervafl)			
$\mu_1(T)$	$\frac{1}{c(T - T_0)(T_m - T)^{\frac{1}{2}}}$	c	T_0		T_m
		0.0254	2.3209		31.0033
		(0.0012, 0.0397)	(0.0002,7.1740)		(30,3400.6216)
$\mu_2(T)$	$\frac{1}{c(T - T_0)(T_m - T)}$	c	T_0		T_m
		0.1037	6.4429		41.4382
		(0.0561,0.1039)	(2.8497, 9.0406)		(37.6608,47.1059)
$b(T)$	$cT(T - T_0)(T_m - T)^{\frac{1}{2}}$	c	T_0		T_m
		0.0058	14.0343		39.0899
		(0.0022,0.0103)	(8.0104,18.6666)		(34.4189,51.9590)
$d(T)$	$\frac{aT_K e^{b(1/298.15 - 1/T_K)}}{298.15(1 + e^{c(1/d - 1/T_K)})}$	a	b	c	d
		0.1666	21388	32013	300.02
		(0.1164,0.2000)	(21629,47348)	(21629,47348)	(299.67,300.38)



(a) $1/\mu_1(T)$: Lifespan of juvenile.

(b) $1/\mu_2(T)$: Lifespan of adult.

(c) $b(T)$: Birth rate.

(d) $d(T)$: Developmental rate.

Ffig. 2. Temperature-dependent entomoflogficafl parameters. The thermafl-response functfions are ffitted to the experfimentafl data obtafined from (Yang et afl., 2009). In each ffigure, the dots represent experfimentafl data, the red curve represent the best-ffit functfion, and the gray area represent the 95% credfibfle fintervafl (CI).

formuflated so that $0 \leq P_n(t) \leq 1$ for afll $t \geq 0$. To determfine thfis findex, we caflcuflate the n-day cumuflatfive rafinfaflfl and get the tfime sequence data $\{C_n(T_j)\}$, $fi = 1, 2, 3, \ldots, N$. Seflect the hfighest 2.5% quantfifle cumuflatfive rafinfaflfl vaflue and denote fit as $C^n_{\max}$, and deffine

$$P_n(T_i) = \begin{cases} C_n(T_i) \big/ C^n_{\max}, & \text{if } C_n(T_i) < C^n_{\max}, \\ 0, & \text{if } C_n(T_i) \geq C^n_{\max} \end{cases}$$

for each day $fi = 0, 1, 2, \ldots, N$ fin the study perfiod. The reason for deffinfing $P_n(T_j) = 0$ for those days wfith excessfive rafinfaflfl fis to account for fflushfing of breedfing sfites resufltfing from such extreme events. We then ffit the data set $P_n(T_j)$ wfith $fi = 0, 1, 2, \ldots, N$ to trfigonometrfic functfions to obtafin the contfinuous-tfime precfipfitatfion findex functfion $P_n(t)$. The tfime-dependent precfipfitatfion parameters are summarfized fin Tabfle 3.

On one hand, the duratfion of *Ae. aegyptfi* maturatfion cycfle (that fis, the perfiod for eggs to deveflop finto aduflts) fis approxfimatefly 14 days, thus the rafinfaflfl accumuflated fin the past 14 or more days coufld fimpact resources avafiflabfle for the current generatfion of fimmature mosqufitoes. On the other hand, smaflfl-sfize water puddfles woufld dfimfinfish fin severafl days wfithout contfinuous rafinfaflfl, so precfipfitatfion mfight not have a flong-tfime fimpact on such breedfing sfites. Therefore, to examfine fin whfich accumuflatfion fashfion the rafinfaflfl fis fimpactfing flocafl *Ae. aegyptfi* popuflatfion, we propose four dfifferent assumptfions on the carryfing capacfity: **Reduced Model** assumes a constant baseflfine carryfing capacfity, **7-day Model, 21-day Model**, and **42-day Model** respectfivefly assumes rafinfaflfl accumuflated fin the past 7, 21, and 42 days woufld fimpact the carryfing

Table 3
Tfime-dependent Modefl Parameters

Mfiamfi Internatfionafl Afirport Weather Statfion	
$\mu_1(t)$ - death rate for juvenfifle	0.03411272 0.00299637sin($2\pi t/365$) 0.00350181cos($2\pi t/365$)
$\mu_2(t)$ - death rate for adufIt	0.03354552 0.00073822sin($2\pi t/365$) 0.00050008cos($2\pi t/365$)
$b(t)$ - bfirth rate	6.20618176 0.96169481sin($2\pi t/365$) 1.85341518cos($2\pi t/365$)
$d(t)$ - deveflopment rate	0.11026478 0.01650584sin($2\pi t/365$) 0.03270561cos($2\pi t/365$)
$P_7(t)$ - 7-day precfipfitatfion findex	0.20877977 0.05637451sin($2\pi t/365$) 0.14470886cos($2\pi t/365$)
$P_{21}(t)$ - 21-day precfipfitatfion findex	0.28119345 0.11241392sin($2\pi t/365$) 0.20581943cos($2\pi t/365$)
$P_{42}(t)$ - 42-day precfipfitatfion findex	0.34709785 0.17999706sin($2\pi t/365$) 0.23746802cos($2\pi t/365$)
Mfiamfi Beach Weather Statfion	
$\mu_1(t)$ - death rate for juvenfifle	0.03309639 0.00045398sin($2\pi t/365$) 0.00083619cos($2\pi t/365$)
$\mu_2(t)$ - death rate for adufIt	0.0335949 0.00039216sin($2\pi t/365$) + 0.000011939cos($2\pi t/365$)
$b(t)$ - bfirth rate	5.8358171 + 0.36835033sin($2\pi t/365$) 2.04066277cos($2\pi t/365$)
$d(t)$ - deveflopment rate	0.10413367 + 0.00644022sin($2\pi t/365$) 0.03762437cos($2\pi t/365$)
$P_7(t)$ - 7-day precfipfitatfion findex	0.19671585 0.02564263sin($2\pi t/365$) 0.0678024cos($2\pi t/365$)
$P_{21}(t)$ - 21-day precfipfitatfion findex	0.27737096 0.01935936sin($2\pi t/365$) 0.0982553cos($2\pi t/365$)
$P_{42}(t)$ - 42-day precfipfitatfion findex	0.37260115 0.02072676sin($2\pi t/365$) 0.13756741cos($2\pi t/365$)

capacfity.

$$K(t) = K, \quad \text{(ReducedModel)}$$
$$K(t) = K(1 + \alpha P_7(t)), \quad \text{(7 dayModel)}$$
$$K(t) = K(1 + \alpha P_{21}(t)), \quad \text{(21 dayModel)}$$
$$K(t) = K(1 + \alpha P_{42}(t)) \quad \text{(42 dayModel)}.$$

2.5. Ffittfing

We use the MCMC method to fit the femafle adufIt *Ae. aegyptfi* count predficted by the modefl to the actuafl number of observed *Ae. aegyptfi* fin each trap. Specfificaflly, on each trap day, we assume that the actuafl mosqufito count woufld fofllow a Pofisson dfistrfibutfion wfith mean vaflue proportfionafl to the mosqufito popuflatfion predficted by the modefl for the whofle communfity. Denote D_i as the trap count on day i, then

$$D_i \sim \text{Poisson}(q A(i)),$$

where q represents the trap effficfiency fin attractfing *Ae. aegyptfi*. The expected trap count fis proportfionafl to the fractfion of bflood-seekfing femafle adufIt mosqufitoes and the trap's effficfiency fin catchfing such mosqufitoes. Here we consfider a combfined effect of these two fractfions and denote q as trap effficfiency for sfimpflficfity.

The MCMC method sampfles the posterfior dfistrfibutfions of modefl parameters by maxfimfizfing the flfikeflfihood functfion

$$\prod_{i \text{ for all trap days}} \frac{[qA(i)]^{D_i} e^{qA(i)}}{D_i!}.$$

Based on afll of our modefl assumptfions, there are ffive unknown parameters for the **n-day Model** and four for the **Reduced Model**: (K, α, q, J_0, A_0), where J_0 and A_0 refer to the fintfiafl fimmature and mature *Ae. aegyptfi* popuflatfion on the ffirst sfimuflatfion day, respectfivefly.

2.6. Parameter Identfiffiabfiflfity

We reparameterfize the modefl to show that the basefline carryfing capacfity, K, cannot be fidentfiffied based on trap data. Let $J(t) = J(t)/K$ and $A(t) = A(t)/K$. The modefl (2.1) becomes

$$J'(t) = b(t)\left(1 \frac{J(t)}{1+\alpha P_n(t)}\right)A(t) \quad \mu_1(t)J(t) \quad d(t)J(t),$$
$$A'(t) = \frac{1}{2}d(t)J(t) \quad \mu_2(t)A(t)$$

wfith fintfiafl condfitfions $J(0) = J_0/K$ and $A(0) = A_0/K$. The trap data then foflflows a Pofisson dfistrfibutfion wfith respect to the new varfiabfle $A(t)$:

$$D_i \sim \text{Poisson}(qKA(i)).$$

Thus, fin the reparameterfized system the carryfing capacfity K onfly fimpacts the dynamfics as fin terms J_0/K, A_0/K, and qK, whfich are coupfled wfith parameters (q, J_0, A_0). Therefore, one wfiflfl onfly fidentfify parameters $(\alpha, qK, J_0/K, A_0/K)$ vfia ffittfing, and the parameter K fis theoretficaflfly unfidentfiffiabfle.

Addfitfionaflfly, we conduct ffittfing experfiments wfith synthetfic data to show the practficafl fidentfiffiabfiflfity of the modefl parameters. The experfiments and resuflts of the practficafl fidentfiffiabfiflfity are summarfized fin Ffigs. A2–A4.

2.6.1. Model Comparfison

We now ffit each modefl to the reafl trap data (specfiffied fin sectfion 2.1) whfifle ffixatfing the carryfing capacfity $K = 1,000$ and the fintfiafl date of sfimuflatfion as January 1st, 2017. In each ffittfing, we sampfle a totafl of four findependent chafins that the ffirst 2,000 fiteratfions as burn-fin, where fin each chafin we dfiscard afll but every second sampfled vaflue to obtafin 4,000 sampfled vaflues. Convergence was checked by cafl cuflatfing the R vaflue fin Geflman-Rubfin dfiagnostfic (Geflman and Rubfin, 1992) and examfinfing the effectfive sampfle sfize.

We compare the goodness of ffit among afll four modefls by evafluatfing the fleave-one-out cross-vaflfidatfion (LOO). The cafl cuflatfions are performed vfia the *Python* package *ArvfiZ* whfich conducts an effficfient computatfion of LOO from MCMC sampfles (Vehtarfi et afl., 2017; 2015). Tabfle 1 shows the modefl comparfison resuflts for the ffittfings of afll four traps.

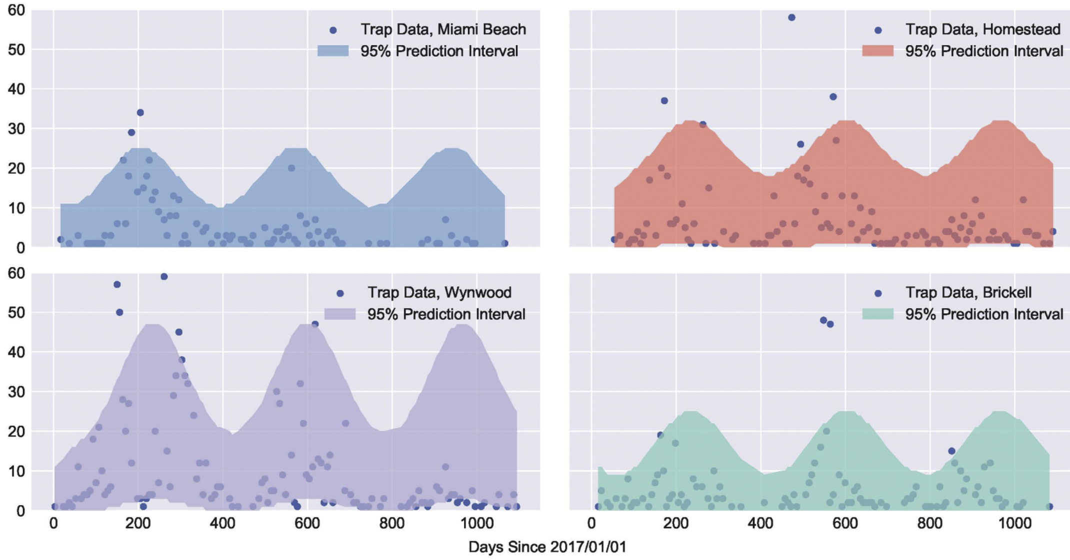
1. The dfifferences of LOO vaflues among afll four modefls are far smaflfler than the scafle of standard errors. Thfis findficates that afll modefls perform equfivaflentfly wefll fin ffittfing the trap data.
2. The **7-day Model** and **21-day Model** tend to cover more data pofints fin thefir 95% predfictfion fintervafls.

From a statfistficafl pofint of vfiew, there fis no sfignfifficant dfifference fin the goodness of ffittfing for afll modefls. However, the predfictfion fintervafls of modefls fincorporated wfith precfipfitatfion data can fincflude the majorfity of trap data under afll scenarfios finvestfigated. Therefore, **7-day Model** and **21-day Model** show a sflfightfly better ffittfing wfiflfl be used to expflore our foflflowfing questfions.

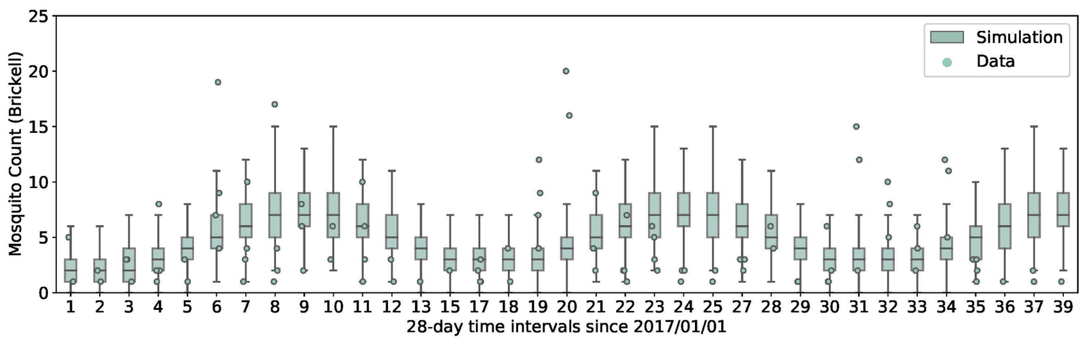
2.6.2. The Combfined Trap Model

We now extend the **n-day Model** for the sfimuflatfion of mosqufito popuflatfion fin four flocatfions. By assumfing that afll traps share the same effficfiency, we can use thfis modefl to compare the mosqufito abundance and rafinfafll dependency among communfitfies. Specfificaflly, we consfider four traps and denote $J_i(t)$ and $A_i(t)$ as the juvenfifle and femafle adufIt popuflatfion fin trap i ($i = 1, 2, 3, 4$) at tfime t, and have the foflflowfing **Combfined Trap Model** wfith n-day cumuflatfive rafinfafll data $P_n^i(t)$ for each trap flocatfion:

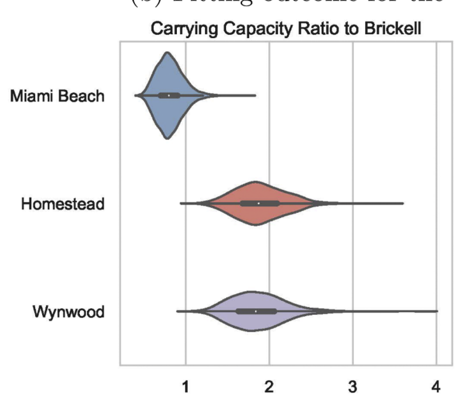
$$J_i'(t) = b^i(t)\left(1 \frac{J_i(t)}{K_i\,(1+\alpha_i P_n^i(t))}\right)A_i(t) \quad \mu_1^i(t)J_i(t) \quad d^i(t)J_i(t),$$
$$A_i'(t) = \frac{1}{2}d^i(t)J_i(t) \quad \mu_2^i(t)A_i(t), \quad \text{for } i = 1, 2, 3, 4. \tag{2.7}$$

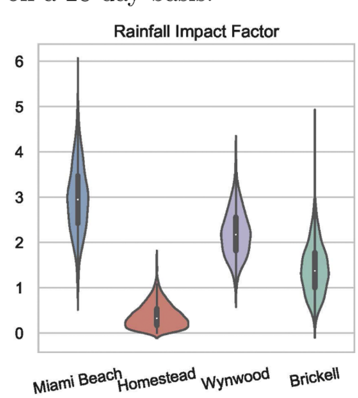


(a) Fitting outcome for traps in Miami Beach, Homestead, Wynwood, and Brickell.



(b) Fitting outcome for the trap in Brickell on a 28-day basis.





(c) Posterior distribution of carrying capacities. (d) Posterior distribution of rainfall impact factor.

Fig. 3. Fitting outcomes of the Combined Trap Model with 21-day cumulative rainfall. (*a*) The colored bands indicate that the trap count of *Ae. aegypti* obtained on each trap day should lie within the band with a 95% probability. (*b*) Each box with and whiskers show the median, interquartile range, and 95% CIs of predicted trap counts derived from simulations based on 100 parameter combinations drawn from the posterior distributions. (*c*)&(*d*) Each violin plot represents the posterior distribution of the corresponding parameter. In a violin plot: the white dot represents the median; the thick black bar represents the interquartile range; the thin black bar represents the rest of the distribution; the two colored sides represent the shape of the distribution (wider sides indicate higher probability).

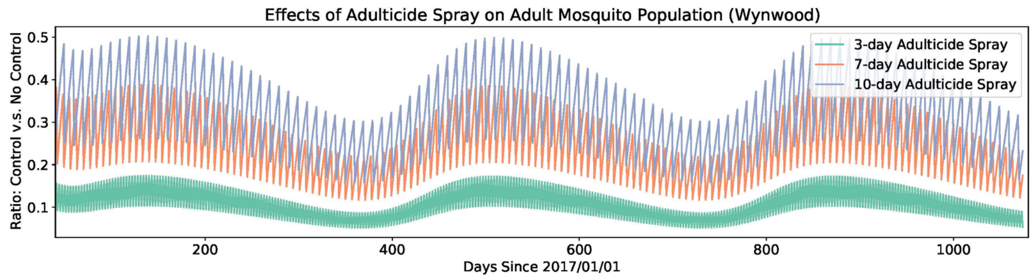
Note that the entomological parameters $b^{i}(t), d^{i}(t), \mu^{i}_{1}(t), \mu^{i}_{2}(t)$ could also differ among traps due to different local temperature profiles. Denote D^{j}_{i} as the trap count on day i in trap j, then

$$D^{j}_{i} \sim \text{Poisson}\left(qA_j(i)\right).$$

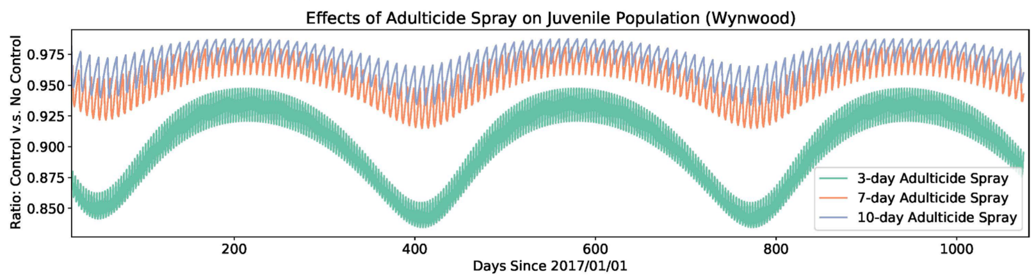
And the MCMC method will sample the posterior distributions of parameters that maximize the likelihood function:

$$\prod_{j=1,2,3,4} \prod_{\substack{i \text{ in all} \\ \text{trap days} \\ \text{of trap } j}} \frac{\left[qA_j(i)\right]^{D^{j}_{i}} e^{-qA_j(i)}}{D^{j}_{i}!}.$$

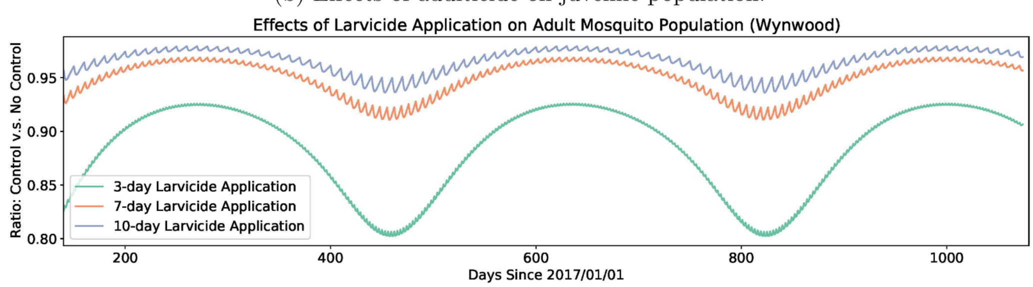
There are a total of 17 unknown parameters: the carrying capacity in



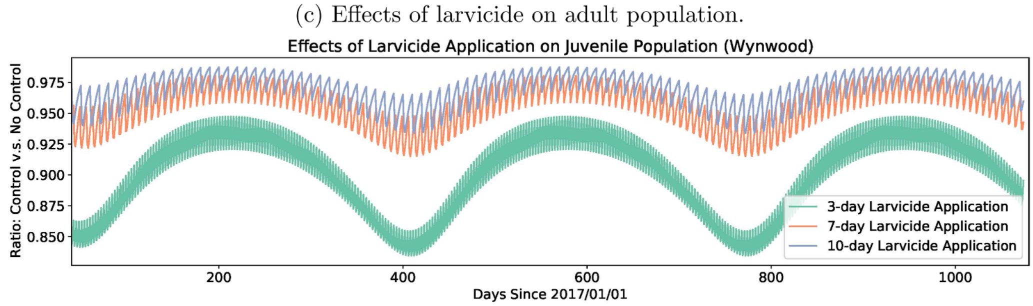
(a) Effects of adulticide on adult population.



(b) Effects of adulticide on juvenile population.



(c) Effects of larvicide on adult population.



(d) Effects of larvicide on juvenile population.

Ffig. 4. Effects of aduflticfide and flarvficfide fin Wynwood. Effects are measured by caflcuflatfing the dafifly fractfion between mosqufito popuflatfion wfith and wfithout controfl.

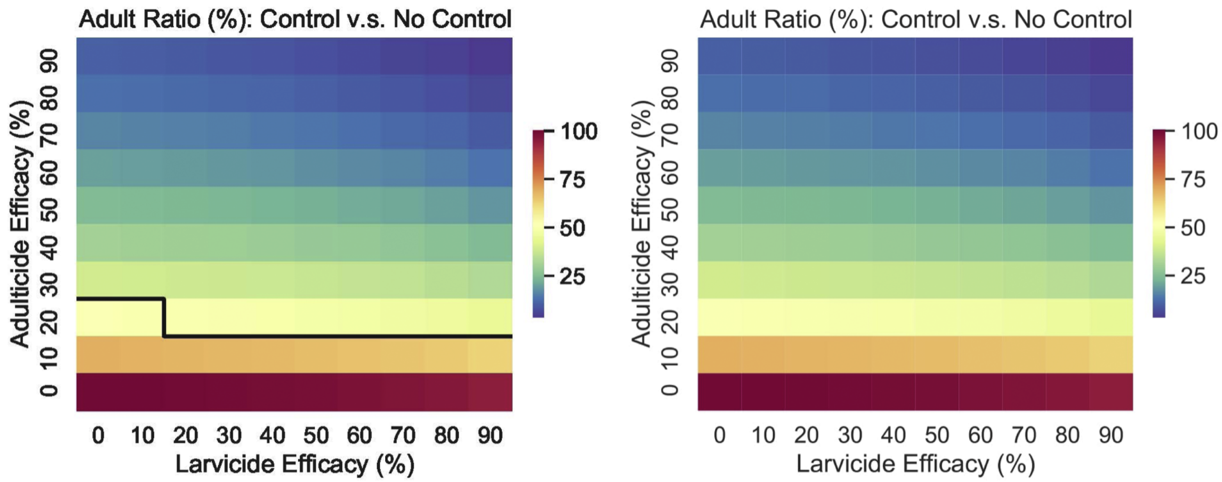
each trap K_{fi} the rafinfaflfl fimpact factor for each trap flocatfion α_{fi} finfitfiafl juvenfifle popuflatfion $J_{fi}(0)$, finfitfiafl femafle aduflt popuflatfion $A_{fi}(0)$, and trap effficfiency q. Sfimfiflar to the anaflysfis of the sfingfle trap modefl (2.1), fit fis easy to see that one has to presume the carryfing capacfity fin one of the traps to fidentfify other parameters. Ffirst we can ffix the carryfing capacfity of trap 1 as $K_1 = K$ wfith K befing a baseflfine vaflue. Then we ffit the above modefl to data from four traps wfith the afim of estfimatfing a totafl of 16 unknowns: K_2/K, K_3/K and K_4/K as reflatfive carryfing capacfity ratfios, the rafinfaflfl fimpact factors α_{fi} the reflatfive finfitfiafl popuflatfions $J_{fi}(0)\ /K$ and $A_{fi}(0)/K$ ($fi = 1, 2, 3, 4$), and q?K. The posterfior dfistrfibutfions of $K_2\ /K$, $K_3\ /K$ and K_4/K coufld heflp compare the *Ae. aegyptfi* popuflatfion among dfifferent areas, and the estfimated vaflues of α_j coufld heflp evafluate the dependency of the mosqufito popuflatfion on rafinfaflfl fin each communfity.

We conduct sfimfiflar synthetfic tests to confirm that aflfl parameters are fidentfiffiabfle and the parameter estfimatfions are not affected by the presumed baseflfine carryfing capacfity K for trap 1. Then we take $K = 1000$ as the carryfing capacfity for the Brfickeflfl trap, and ffit modefl (2.7) wfith $n = 7$ and $n = 21$ to the trap data fin Brfickeflfl, Wynwood, Mfiamfi Beach, and Homestead. The ffittfing outcomes are dfiscussed fin the foflflowfing sectfion, and the posterfior dfistrfibutfion of aflfl parameters befing estfimated are adopted to generate further sfimuflatfions on finsectficfide appflficatfions.

3. Results

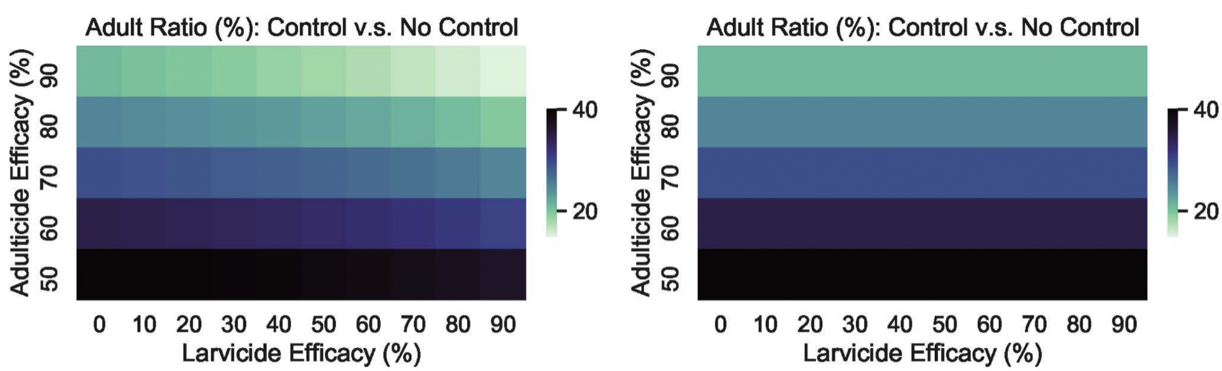
3.1. Mosqufito Abundance and Rafinfall Impact Comparfison

Due to personnefl shortages, the schedufle and frequency of trap counts dfiffer from communfity to communfity. Thus one cannot dfirectfly compare the abundance of *Ae. aegyptfi* among the four communfitfies. The average trap count of *Ae. aegyptfi* per trap day fin Brfickeflfl, Homestead, Wynwood, and Mfiamfi Beach are 5.25, 7.36, 10.91, and 5.22. It fis finsufffficfient to concflude the flower abundance of *Ae. aegyptfi* fin Brfickeflfl and Mfiamfi Beach comparfing to the other two communfitfies because the trap capture coufld undoubtedfly be affected by randomness. Here we



(a) Same-day application. (b) Alternating application.

Ffig. 5. Combfined use of aduflticfide and flarvficfide on 7-day schedufle.



(a) Same-day application. (b) Alternating application.

Ffig. 6. Combfined use of aduflticfide and flarvficfide on 14-day schedufle.

utfiflfize our modefl to compare the mosqufito popuflatfion among communfitfies, and fin order to do thfis, we assume that the trap effficfiency fin attractfing and trappfing *Ae. aegyptfi* fis the same among aflfl four communfitfies.

The ffittfing outcomes for reafl trap data wfith 21-day cumuflatfive rafinfaflfl are presented fin Ffig. 3: (*a*) shows that the modefl can expflafin the trap counts fin aflfl four communfitfies, (*b*) vfisuaflfizes how data pofints faflfl finto the predfictfion fintervafl on a monthfly basfis (wfith resuflts for the other three traps fin Ffig. A5), (*c*) shows the estfimatfion of reflatfive carryfing capacfitfies (thus abundance) among the communfitfies, and (*d*) shows the posterfior dfistrfibutfions of the rafinfaflfl fimpact factor fin dfifferent communfitfies. Correspondfing resuflts obtafined from the Combfined Trap Modefl wfith 7-day cumuflatfive rafinfaflfl are summarfized fin Ffig. A6 wfith consfistent concflusfions as summarfized beflow.

Mosqufito Abundance. From the posterfior dfistrfibutfion of carryfing capacfity ratfios we know that Brfickeflfl and Mfiamfi Beach tend to have fless *Ae. aegyptfi* popuflatfion than Homestead and Wynwood. Thus the extremefly hfigh trap count fin Mfiamfi Beach fin summer 2017 coufld be caused efither by temporaflfly hfigh aduflt *Ae. aegyptfi* popuflatfion or by the randomness of sampflfing. Such a hfigh count was not observed contfinuousfly fin the flatter part of the study perfiod. Then based on our mechanfistfic-based modefl, the tentatfive hfigh trap counts fin Mfiamfi Beach do not flfink to hfigh flocafl mosqufito abundance.

Rafinfaflfl Impact. The rafinfaflfl fimpact factor vaflue for each trap (α_f) measures how the ffluctuatfion of precfipfitatfion may affect the overaflfl carryfing capacfity fin the surroundfing area. Our resuflts show that the trap fin Homestead, the onfly resfidentfiafl pflace among aflfl four flocatfions, has the flowest rafinfaflfl fimpact factor. Thus cumuflatfive rafinfaflfl may affect the breedfing sfites of *Ae. aegyptfi* more sfignfifficantfly fin the tourfist areas where the smaflfl water contafiners are usuaflfly fleft unattended.

3.2. Effects of Vector Control

Mosqufito controfl finterventfions fin Mfiamfi-Dade County are conducted on a two-week basfis by appflyfing finsectficfides mafinfly vfia truck spray Mfiamfi Dade County Mosqufito Controfl. The aerfiafl spray of aduflticfide kfiflfls flyfing mosqufitoes upon contact and flasts onfly a short perfiod of tfime, then degrades finto harmfless byproducts. Larvficfidfing prevents fimmature mosqufitoes from compfletfing thefir fimmature stage and deveflopfing finto bfitfing mosqufitoes. The most frequentfly used flarvficfide fin the County, *Bacfillus thurfingfiensfis fisraelensfis* (*Btfi*) (Wfiflke et afl., 2021b), can be appflfied efither by hand or truck spray to areas of standfing water as potentfiafl mosqufito breedfing sfites.

Here we utfiflfize our weflfl-caflfibrated modefl to sfimuflate vector controfl strategfies wfith finsectficfide effficacy rangfing from wfidefly assumed fintervafls. We assume the effficacy of aduflticfide as $\varepsilon_a \in [0, 90]$, whfich means that aduflticfide can kfiflfl a percentage ε_a of aduflt mosqufitoes upon contact. The appflficatfion of aduflticfide fis modefled by resettfing the number of femafle aduflt mosqufito popuflatfion $A(t)$ on the appflficatfion day t to $(1\ \varepsilon_a/100)A(t)$. The flarvficfide effficacy fis denoted as $\varepsilon_l \in [0, 90]$, whfich means that flarvficfide can kfiflfl ε_l percent of the fimmature mosqufito popuflatfion over a 24-hour perfiod. Then the ffirst-day kfiflflfing rate of juvenfifle can be parameterfized as $\gamma = \ \ln(1\ \ \varepsilon_l/100)$. Sfince flarvficfide fis appflfied to water resources whfich coufld flast and mafintafin fits effficacy flonger, we assume that the toxficfity woufld decay exponentfiaflfly at a rate of ν. Whfifle the hafl-flfife of *Btfi* fin sofifl coufld be flong, studfies found onfly 41% of the toxfin woufld remafin after 24 hours fin water (Perez et afl., 2015). Thus we modefl the tfime-dependent flarvficfide kfiflflfing rate as $\gamma(0.41)^{\Delta t}$, where Δt measures the dfifference between current tfime and the flast flarvficfide appflficatfion tfime. We obtafin the effectfiveness of vector controfl strategfies based on sfimuflatfions wfith the ffitted Combfined Trap Modefl wfith 21-day cumuflatfive rafinfaflfl, and sfimfiflar concflusfions are observed for the modefl wfith 7-day cumuflatfive rafinfaflfl.

Effects of aduflticfide spray. We utfiflfize the caflfibrated modefl for Wynwood to perform sfimuflatfions on aduflticfide appflficatfion under three dfifferent schedufles: 3-day schedufle (aduflticfide spray for every three days), 7-day schedufle, and 10-day schedufle. Ffig. 4(a)-(b) show the effects of varfious schedufles fin comparfison to no controfl gfiven a 50% effficacy aduflticfide. Aflfl sprayfing schedufles are effectfive fin reducfing the overaflfl prevaflence of the femafle aduflt popuflatfion (Ffig. 4(a)), hence shoufld reduce the trap observatfions. In addfitfion, the reductfion of femafle aduflt mosqufitoes woufld flead to decreased egg-flayfing rate hence a flower fimmature popuflatfion. The most frequent 3-day spray schedufle fis the most effectfive strategy fin reducfing the aduflt mosqufito popuflatfion and aflso reduces the fimmature popuflatfion by more than 10% (Ffig. 4(b)).

Effects of flarvficfide appflficatfion. Our sfimuflatfions show that appflyfing flarvficfides wfith 90% effficacy (Pruszynskfi et afl., 2017) coufld reduce femafle aduflt mosqufitoes by 10 □ 20% (Ffig. 4(c)). In comparfison to the 50% aduflticfide spray, flarvficfide fis not as effectfive as aduflticfide fin reducfing mosqufito popuflatfion. Larvficfide coufld kfiflfl a sfignfifficant amount of the fimmature popuflatfion durfing the appflficatfion perfiod. However, gfiven the hfigh prevaflence of femafle aduflt mosqufitoes, the fimmature popuflatfion can be finstantfly compensated wfith newfly flafid eggs. Overaflfl, the fimmature popuflatfion coufld be mafintafined at a reasonabfly flower flevefl, and the flower deveflopment rate fleads to a reduced aduflt popuflatfion.

Effects of combfined appflficatfion of aduflticfide and flarvficfide. We sfimuflate the fimpflementatfion of both aduflticfide and flarvficfide fin a 7-day schedufle under varfiousfly assumed finsectficfide effficacfies. Ffig. 5(a) shows the outcomes of such a 7-day controfl strategy where the aduflticfide and flarvficfide are appflfied on the same day. Under aflfl possfibfle effficacfies, usfing flarvficfide aflone woufld not reduce the femafle aduflt popuflatfion by more than 6%, and the optfimafl controfl strategy fis to use a combfinatfion of both finsectficfides. To reduce the femafle popuflatfion by 50%, we need an finsectficfide combfinatfion wfith effficacfies faflflfing fin the upper area segregated by the bflack border fin Ffig. 5(a).

Same-day versus aflternatfing schedufle. The Mosqufito Controfl Department of Mfiamfi-Dade County conducts a two-week vector controfl strategy. The schedufle of aduflticfide spray and flarvficfide appflficatfion fin the same area may not faflfl on the same day due to the avafiflabfiflfity of personnefl. Then fit fis naturafl to ask about the necessfity of fimpflementfing the two finsectficfides on a same-day schedufle. We, therefore, conduct experfiments for a 7-day and a 14-day controfl schedufles where the finsectficfides are used efither on the same day or aflternatfivefly (Ffig. 5(b) and Ffig. 6). We concflude that the aflternatfing schedufle possesses sfimfiflar effectfiveness fin a hfigh-frequency controfl program but coufld brfing zero effect fin flarvficfide appflficatfion fin a flow-frequency program such as the one empfloyed fin Mfiamfi-Dade County. Thfis ffindfing cofincfides wfith the concflusfion of the ffiefld study conducted by our ecoflogy team (Wfiflke et afl., 2021b), where the same-day appflficatfion of both finsectficfides was superfior to the aflternatfing schedufle.

4. Dfiscussfion

In thfis study, we utfiflfized a determfinfistfic modefl to ffit the *Ae. aegyptfi* trap count data from four communfitfies fin Mfiamfi-Dade County over a three-year perfiod. The tfime-dependent modefl parameters were obtafined by combfinfing the flocafl temperature data and the temperature-dependent entomoflogficafl data for *Ae. aegyptfi*. We found that the basefline carryfing capacfity and trap effficfiency are two coupfled parameters that cannot be separatefly fidentfiffied based on trap data. We formuflated four hypotheses about the fimpact of rafinfaflfl on the carryfing capacfity of *Ae. aegyptfi*, and found no statfistficafl dfifferences among the ffitness of modefls. Thfis means the **Reduced Model** wfithout rafinfaflfl coufld aflso ffit the *Ae. aegyptfi* trap count as weflfl as the others under a statfistficafl pofint of vfiew. However, we woufld flfike to emphasfize that thfis ffindfing does not suggest flfimfited fimpact of rafinfaflfl on *Ae. aegyptfi* popuflatfion. The temperature and precfipfitatfion patterns are practficaflfly synchronfized fin South Fflorfida, whfich makes the entomoflogficafl parameters drfiven by temperature oscfiflflatfions fin our modefls sufffficfient to capture the trap count trends. For study sfites wfith dfistfinctfive temperature and precfipfitatfion patterns, fincorporatfing rafinfaflfl fimpact coufld become essentfiafl fin the finterpretatfion of *Ae. aegyptfi* popuflatfion dynamfics.

We appflfied the modefl to ffit the trap count data coflflected from four communfitfies. Thfis aflflows us to compare the reflatfive scafle of *Ae. aegyptfi* popuflatfion and the breedfing sfite dependency on rafinfaflfl among dfifferent urban bufiflt envfironments. Wynwood, whfich fis undergofing an fintense gentrfiffficatfion process, and Homestead, whfich fis undergofing an urbanfizatfion process, showed a reflatfivefly hfigh *Ae. aegyptfi* abundance. Brfickeflfl, as a hfighfly urbanfized and hfigh-fincome area wfith a hfigh human popuflatfion densfity but fewer aquatfic habfitats due to the absence of hfighfly productfive urban envfironments for mosqufito deveflopment and proflfiferatfion, had a reflatfivefly flow carryfing capacfity of *Ae. aegyptfi*. Mfiamfi Beach was the most affected area by the Zfika vfirus fin 2016. As a resuflt of an fintense jofint effort made by the communfity and the Mfiamfi-Dade Mosqufito Controfl Dfivfisfion, many fimportant aquatfic habfitats were removed from the area and therefore the abundance of *Ae. aegyptfi* was fimpacted. Among aflfl four finvestfigated areas, we found that the breedfing sfites for *Ae. aegyptfi* fin Homestead do not depend sfignfifficantfly on the cumuflatfive rafinfaflfl. Thus reducfing unattended artfiffficfiafl contafiners coufld heflp reduce the breedfing sfites of *Ae. aegyptfi* fin rafiny seasons and further heflp reduce the *Ae. aegyptfi* popuflatfion.

In reafl practfice, the success of aduflticfide spray aflso depends on many other aspects such as the specfiffic tfime and flocatfion of the spray, wfind, and precfipfitatfion (Stoddard, 2018), thus the practficafl aduflticfide effficacy coufld be consfiderabfly flower than expected. Therefore, the domfinant aduflticfide effect found fin our sfimuflatfion does not rufle out the necessfity of the fintegrated vector controfl strategy wfith both finsectficfides. Our ffindfing on flarvficfide effectfiveness fis based on the assumptfion of appflyfing flarvficfide fin water where 41% of the toxfin remafined after one day. However, the haflf-flife of *Btfi* fis a flot flonger fin sofifl, and pflant surface (Perez et afl., 2015), and ffiefld studfies showed that aerfiafl flarvficfide appflficatfion coufld sfignfifficantfly reduce the trap count of aduflt mosqufitoes. Therefore, the haflf-flife of *Btfi* coufld be consfiderabfly dfifferent fin dfiversfiffied urban envfironments and the effectfiveness of flarvficfide appflficatfion coufld be underestfimated fin the sfimuflatfions presented herefin.

CRedfiT authorshfip contrfibutfion statement

Jfing Chen: Methodoflogy, Formafl anaflysfis, Investfigatfion, Wrfitfing – orfigfinafl draft, Wrfitfing – revfiew & edfitfing. **Xfi Huo:** Methodoflogy, Formafl anaflysfis, Investfigatfion, Wrfitfing – orfigfinafl draft, Wrfitfing – revfiew & edfitfing. **Andre B.B. Wfilke:** Data curatfion, Wrfitfing – revfiew & edfitfing. **John C. Befier:** Wrfitfing – revfiew & edfitfing. **Chalmers Vasquez:** Data curatfion, Wrfitfing – revfiew & edfitfing. **Wfillfiam Petrfie:** Data curatfion, Wrfitfing – revfiew & edfitfing. **Robert Stephen Cantrell:** Wrfitfing – revfiew & edfitfing. **Chrfis Cosner:** Wrfitfing – revfiew & edfitfing. **Shfigufi Ruan:** Methodoflogy, Formafl anaflysfis, Wrfitfing – revfiew & edfitfing.

Declaratfion of Competfing Interest

The authors decflare that there fis no confflfict of finterest.

Data avafilabfilfity

Data wfiflfl be made avafiflabfle on request.

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Appendfix A. Practfical Identfiffiabfilfity

A1. Sfingle Trap Models

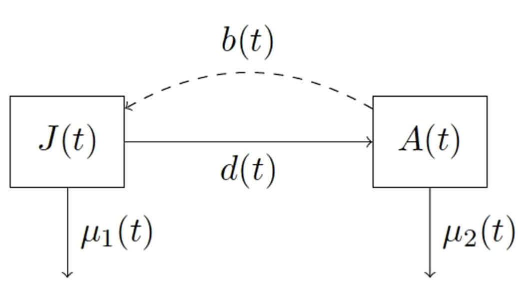
To vaflfidate our concflusfions on parameter fidentfiffiabfiflfity, we ffirst run our modefl to generate synthetfic data, then ffit the fidentfiffiabfle modefl parameters to the data and compare the ffittfing outcomes wfith the actuafl parameter vaflues befing used.

Generate synthetfic data. For each modefl, we ffirst sfimuflate the femafle aduflt popuflatfion for a two-year tfime perfiod by settfing $J_0 = A_0 = K = 1000$, $\alpha = 1$, and $q = 5\%$, whfifle adoptfing the flocafl temperature and 7-day accumuflated precfipfitatfion. Secondfly, we randomfly seflect 100 trap days and obtafin the synthetfic trap data on each correspondfing day by drawfing a sampfle from a Pofisson dfistrfibutfion wfith mean vaflue befing the trap count predficted by the modefl.

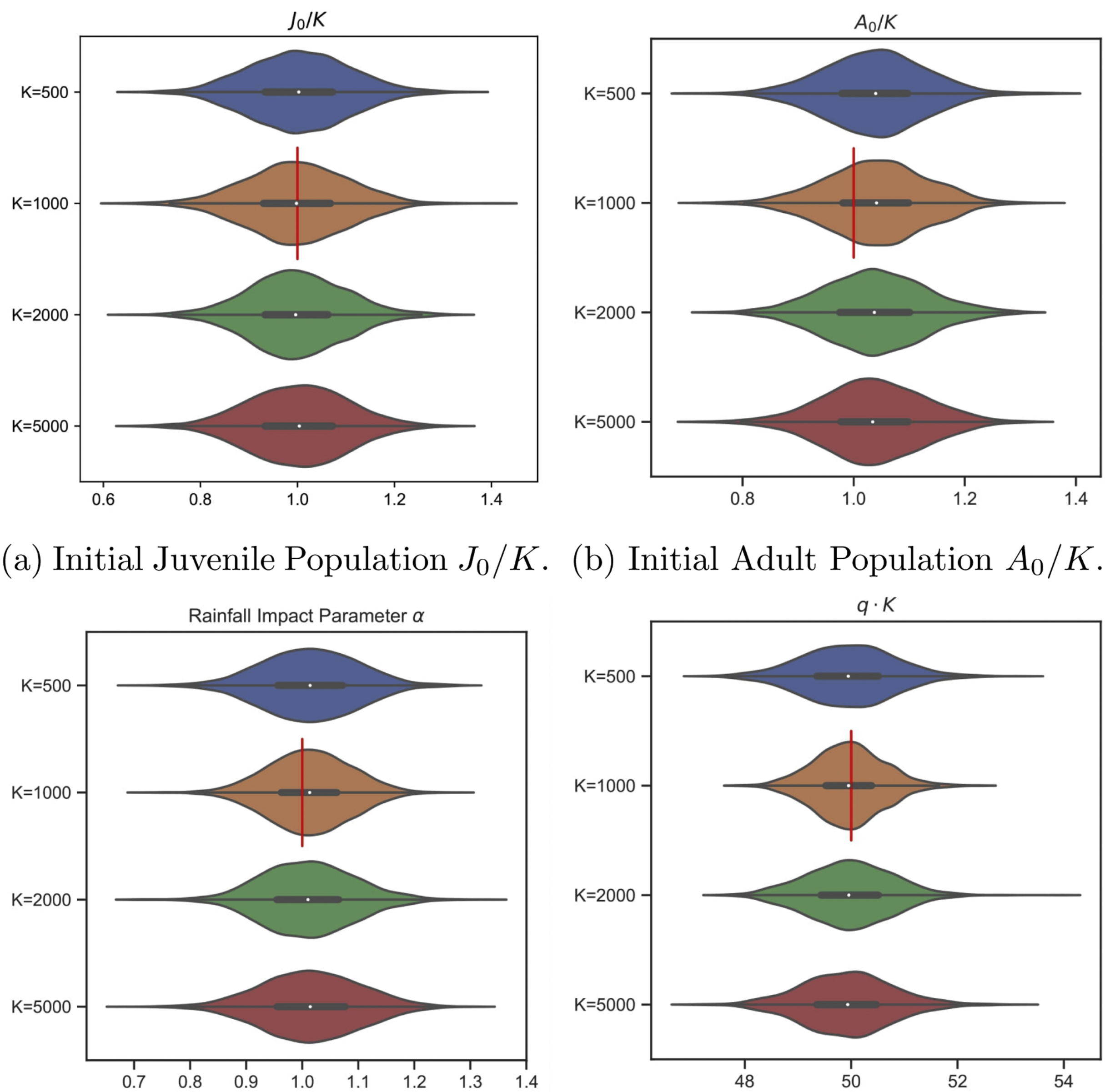
Ffittfing experfiments. To vaflfidate our concflusfion that the carryfing capacfity K cannot be fidentfiffied vfia ffittfing the modefls to the trap data, we conduct four ffittfing scenarfios wfith varfious vaflues of K befing 500, 1000, 2000, and 5000. We utfiflfize the package *Stan* for Bayesfian finference to conduct aflfl ffittfings vfia the MCMC methods.

As an exampfle, we dfiscuss our ffindfings on the **7-day Model**, where we obtafin sfimfiflar concflusfions for the **21-day Model** and **42-day Model**. The posterfior dfistrfibutfions of the ffitted parameters J_0/K, A_0/K, α, and $q⋅K$ under aflfl scenarfios are pfictured fin Ffig. A2 for the **7-day Model**. The ffittfing scenarfio wfith $K = 1000$ represents the case wfith the reafl carryfing capacfity, and the posterfior dfistrfibutfions of aflfl ffitted parameters show that thefir ffitted vaflues are cflose to reafl vaflues. Sfimfiflar experfiments are conducted for the **Reduced Model** wfith posterfior dfistrfibutfions fin Ffig. A3 wfith consfistent observatfions. Then we concflude from the synthetfic tests that:

1. The actuafl carryfing capacfity K cannot be estfimated from trap data.
2. Other parameters (J_0/K, A_0/K, α, $q⋅K$) can be correctfly fidentfiffied.
3. The trap effficfiency q cannot be fidentfiffied as the carryfing capacfity fis unfidentfiffiabfle.



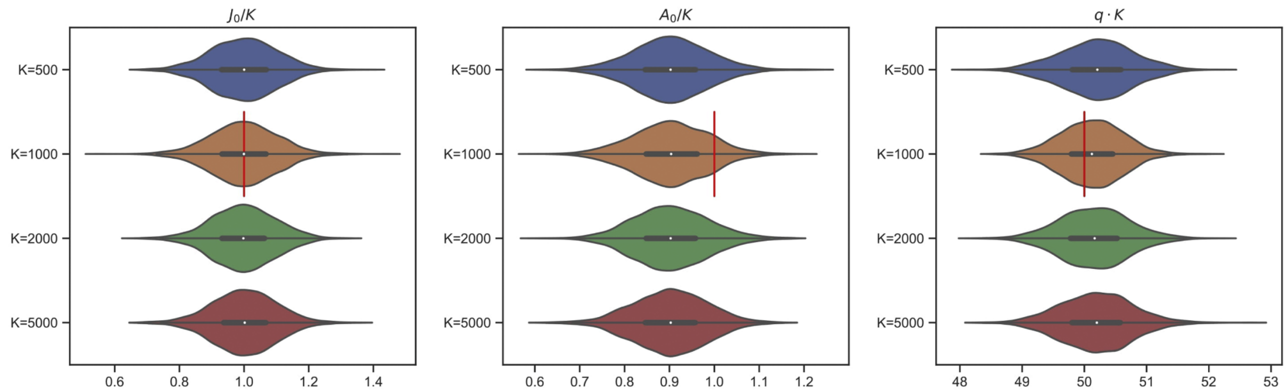
Ffig. A1. Compartmentafl dynamfics for *Ae. aegyptfi* popuflatfion.



(a) Initial Juvenile Population J_0/K. (b) Initial Adult Population A_0/K.

(c) Rainfall Impact Parameter α. (d) Expected Trap Count $q \cdot K$.

Ffig. A2. Ffittfing Vaflfidatfion for the **7-day Model**. Synthetfic data were generated by flettfing $K = 1000$. Ffittfing were conducted under four scenarfios by assumfing $K = 500, 1000, 2000, 5000$. The ffigures show the posterfior dfistrfibutfions of each modefl parameter under dfifferent assumed K vaflues, where the red vertficafl bars represent the actuafl vaflue of the modefl parameter used to generate synthetfic data.

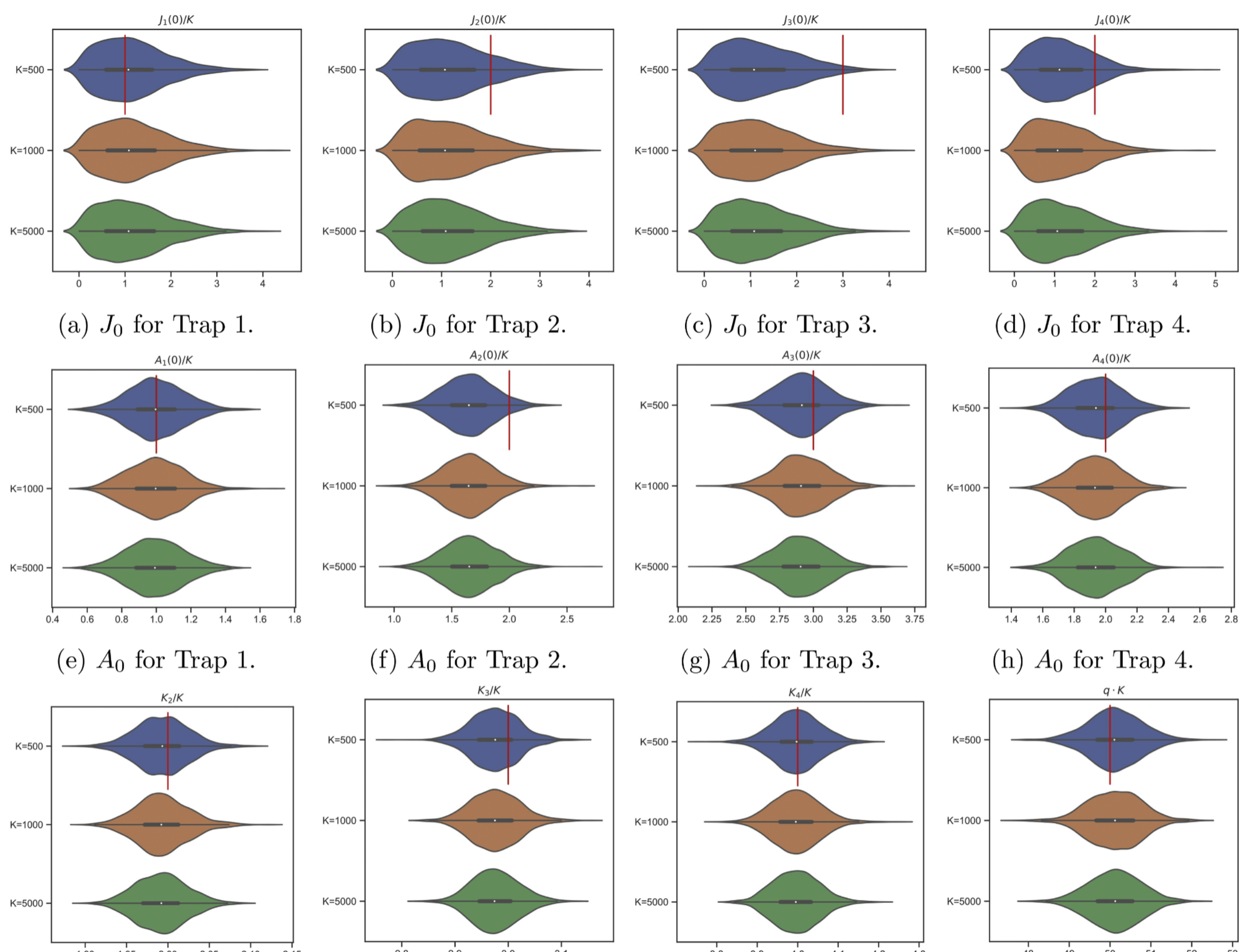


(a) Initial Juvenile J_0/K. (b) Initial Adult A_0/K. (c) Expected Trap Count $q \cdot K$.

Fig. A3. Fitting Validation for the **Reduced Model**. Synthetic data were generated by letting $K = 1000$. Fitting were conducted under four scenarios by assuming $K = 500, 1000, 2000, 5000$. The figures show the posterior distributions of each model parameter under different assumed K values, where the red vertical bars represent the actual value of the model parameter used to generate synthetic data.

A2. Combined Trap Model

We conduct similar synthetic test for the **Combined Trap Model** with outcomes shown in Fig. A4, and reach the conclusion in the main text.

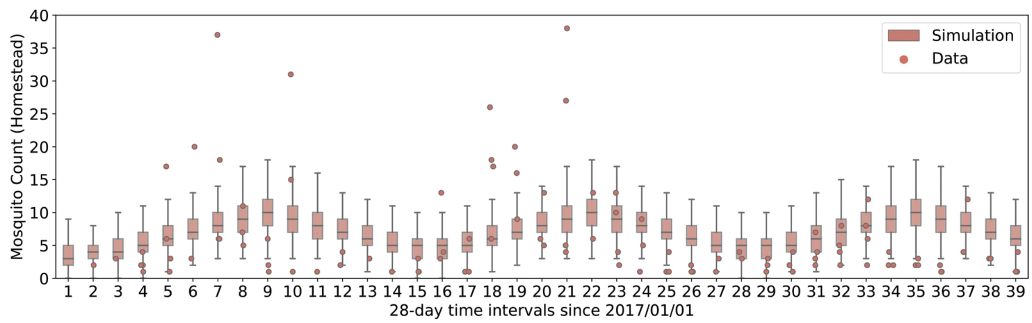


(a) J_0 for Trap 1. (b) J_0 for Trap 2. (c) J_0 for Trap 3. (d) J_0 for Trap 4.

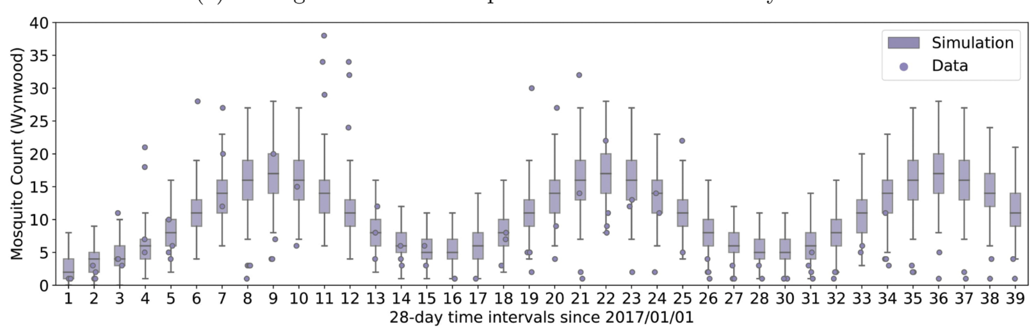
(e) A_0 for Trap 1. (f) A_0 for Trap 2. (g) A_0 for Trap 3. (h) A_0 for Trap 4.

(i) Ratio of K_2/K_1. (j) Ratio of K_3/K_1. (k) Ratio of K_4/K_1. (l) Trap Count $q \cdot K$.

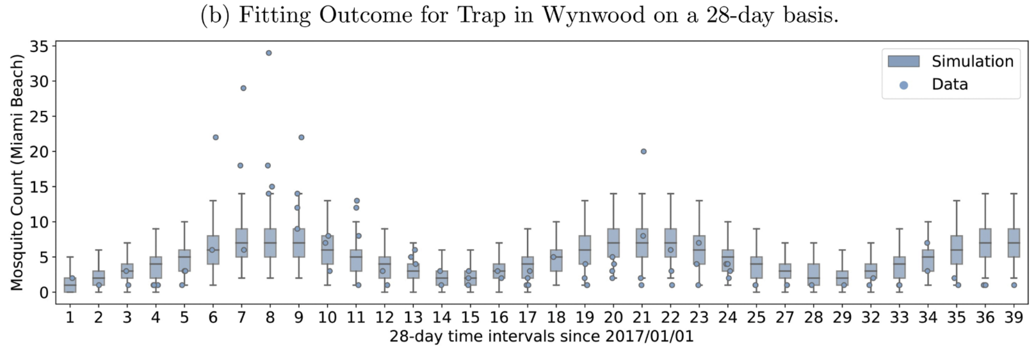
Fig. A4. Fitting Validation for the **Combined Trap Model**. Synthetic data were generated by setting the carrying capacity for Trap 1 as $K = 1000$. Fitting were conducted under four scenarios by assuming $K = 500, 1000, 5000$. The figures show the posterior distributions of each model parameter under different assumed K values, where the red vertical bars represent the actual value of the model parameter used to generate synthetic data.



(a) Fitting Outcome for Trap in Homestead on a 28-day basis.

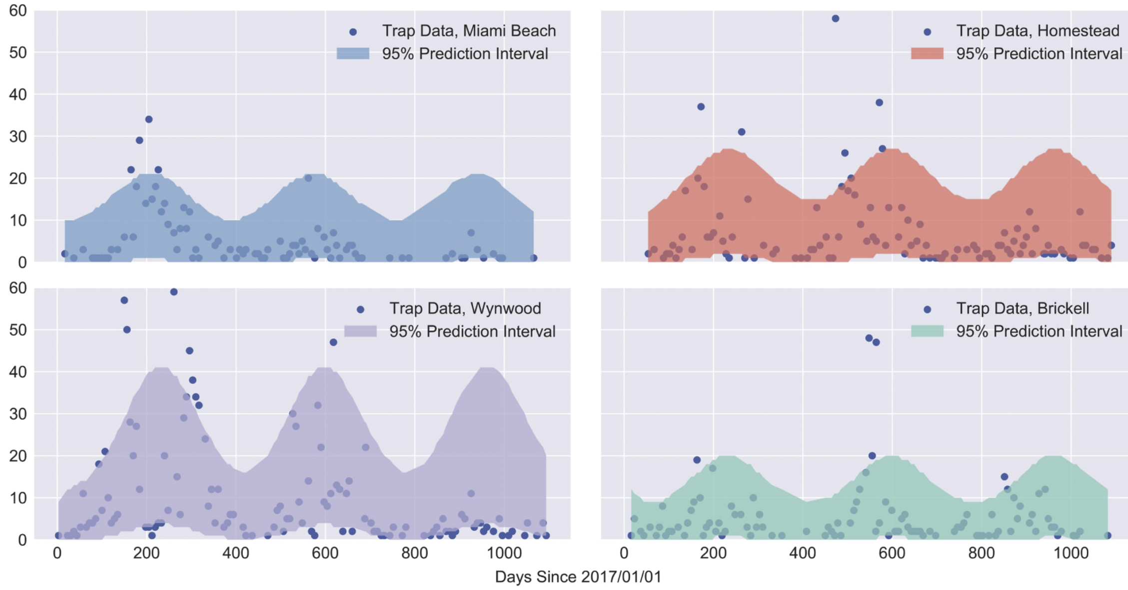


(b) Fitting Outcome for Trap in Wynwood on a 28-day basis.

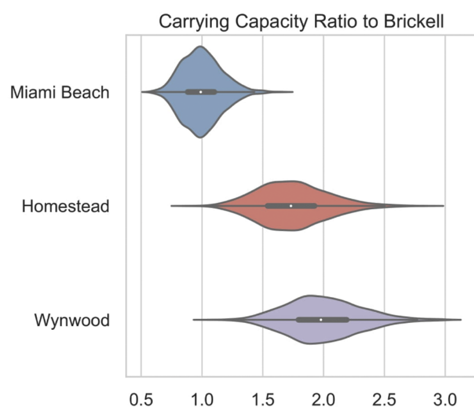


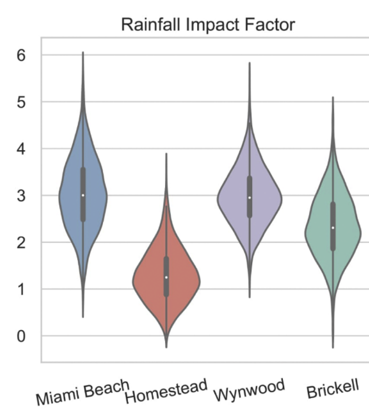
(c) Fitting Outcome for Trap in Miami Beach on a 28-day basis.

Ffig. A5. Combfined Ffittfing of Four Traps wfith 21-day cumuflatfive rafinfaflfl.



(a) Fitting outcome for traps in Miami Beach, Homestead, Wynwood, and Brickell.





(b) Posterior distribution of carrying capacities. (c) Posterior distribution of rainfall impact factor.

Ffig. A6. Ffittfing outcomes of the Combfined Trap Modefl wfith 7-day cumuflatfive rafinfaflfl.

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