Modelling the risk of introduction of urban yellow fever, Zika virus and chikungunya fever in Aedes infested areas

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MEDICINA
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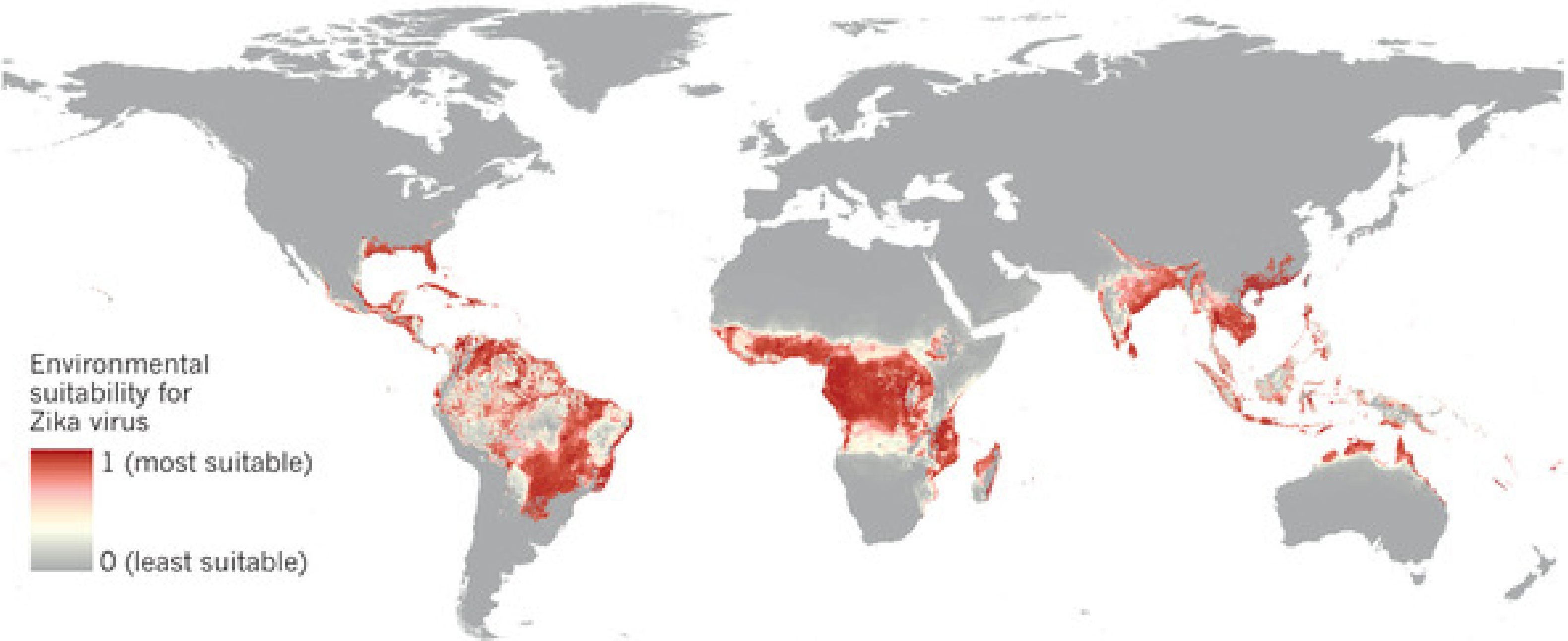
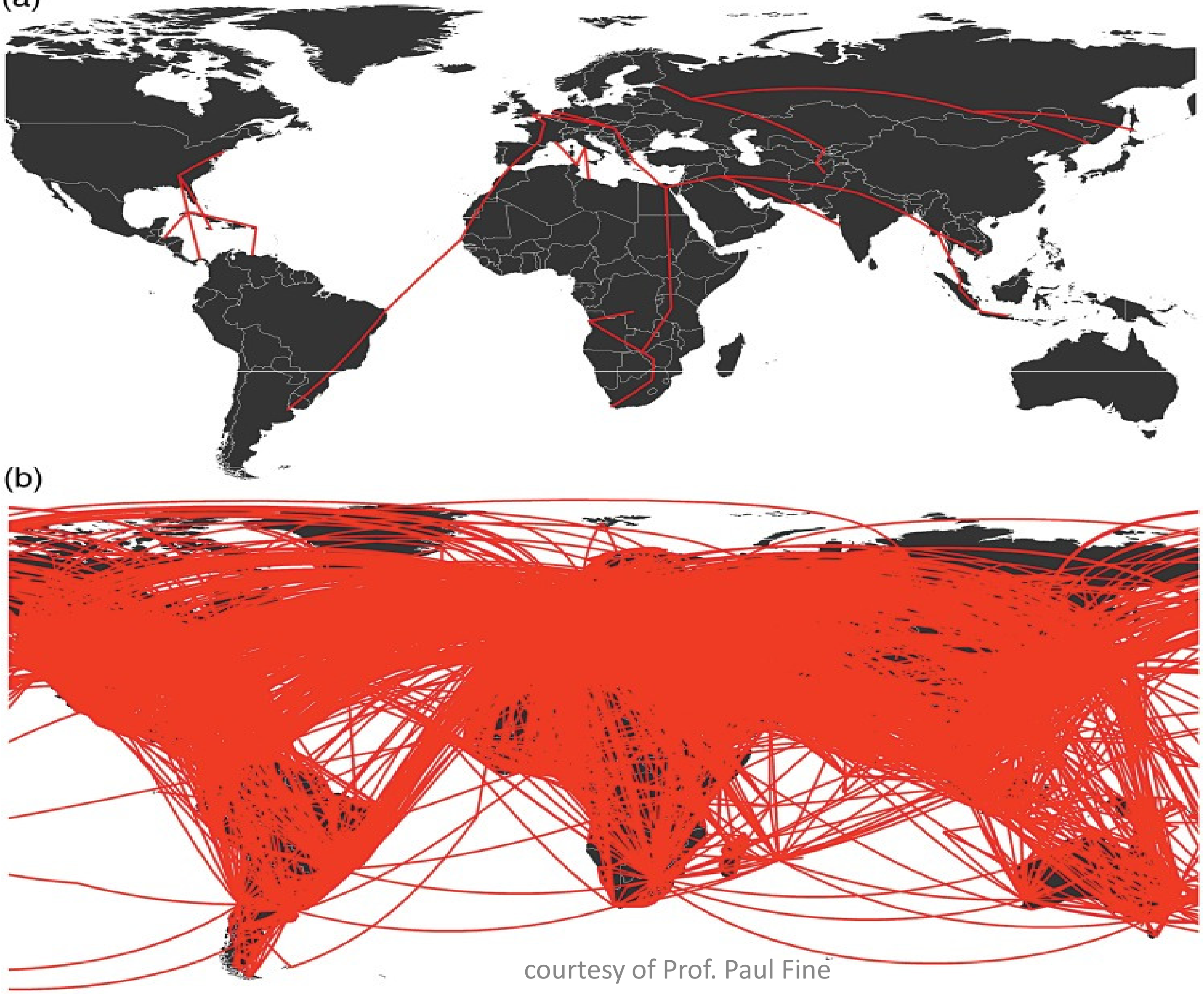

Environmental
suitability for
Zika virus
1 (most suitable)
0 (least suitable)

Global spread of infection
a function of air travel networks ….

(a)

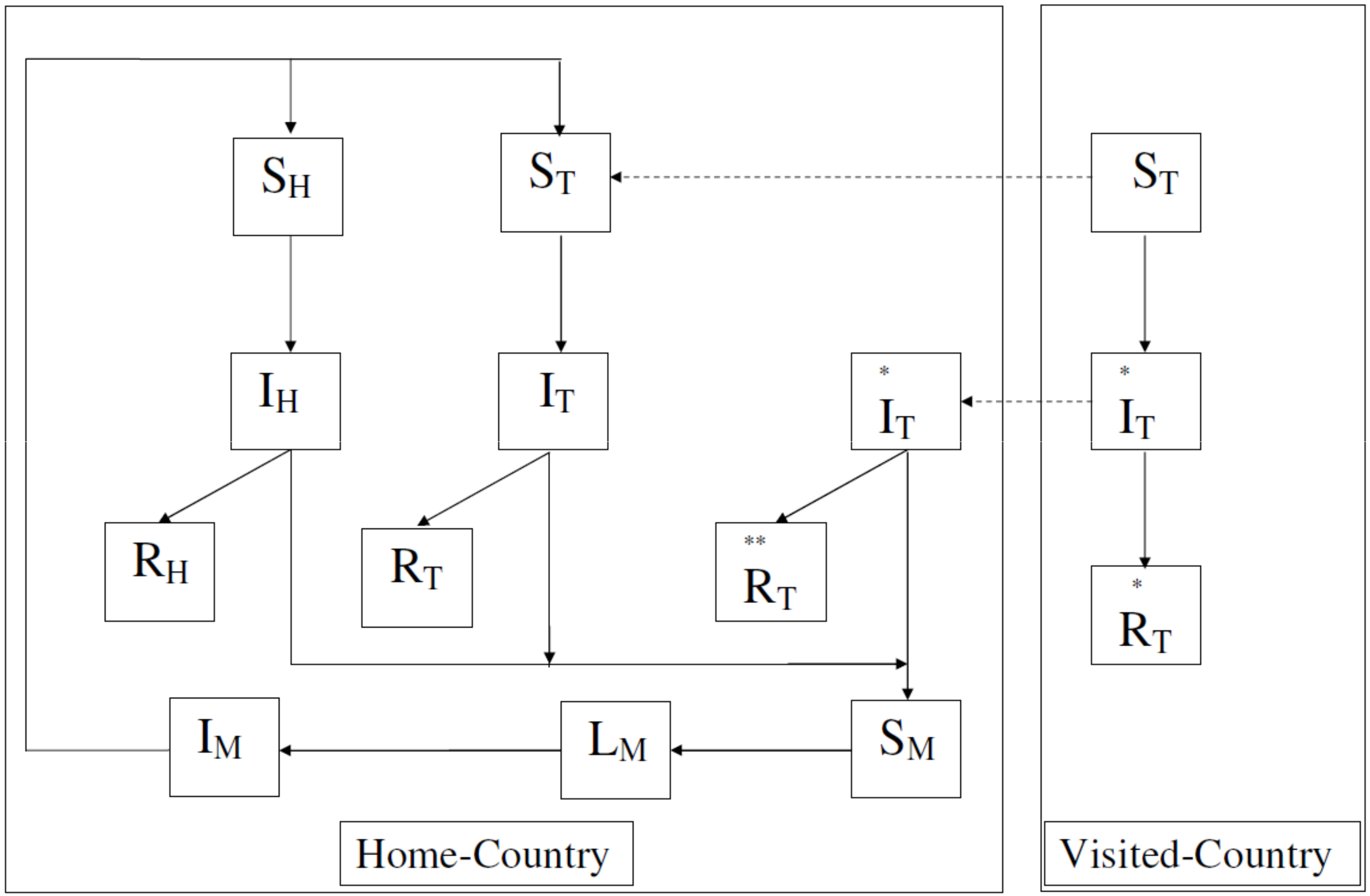


(b)

1933

2010

courtesy of Prof. Paul Fine



S_H
S_T
S_T
I_H
I_T
I_T^*
I_T^*
R_H
R_T
R_T^{**}
R_T^*
I_M
L_M
S_M
Home-Country
Visited-Country

Table 1 Descriptions of the subpopulations

Class	Description
S_H	Susceptible individuals who never travelled to the endemic country
I_H	Individuals who acquired the infection in their home-country (authoctonous)
R_H	Authoctonous cases who recovered from the infection
S_T	Susceptible travellers who returned susceptible to their home-country
I_T	Autocthonous cases among returning travellers
R_T	Recovered individuals from I_T class
$\overset{*}{S}_T$	Susceptible travellers who are returning susceptible to their home-country
$\overset{*}{I}_T$	Travellers who acquired the infection at the visited country and return infectious
$\overset{*}{R}_T$	Recovered individuals from $\overset{*}{I}_T$ class in the visited country
$\overset{**}{R}_T$	Recovered individuals from $\overset{*}{I}_T$ class in the home-country
S_M	Susceptible mosquitoes at the home-country
L_M	Latent mosquitoes at the home-country
I_M	Infectious mosquitoes at the home-country (infected by I_H, I_T, and $\overset{*}{I}_T$)

Model's assumptions

The model assumes a vector-borne infection characteristic of tropical regions. Its vector, however, is also present in some disease-free countries. The model will be exemplified by dengue fever and the risk of its introduction into Europe.

Two important assumptions characterize the model: first, travellers are subject to the same risk of infection as residents from the endemic and visited country; and second, the visitors are few individuals with respect to the visited country population and stay for a relatively short period. Therefore, it is possible to assume that they do not contribute to the local force of infection.

$$I^{(3)}(T_O) = \int_0^{T_O} dT_R \int_0^{T_R} dT_{GB} \int_0^{T_{GB}} dT_I S(0) e^{-\int_0^{T_I} \lambda(s)ds - (\mu+\sigma)T_I} \lambda(T_I) e^{-(\mu+\gamma+\sigma)(T_{GB}-T_I)} \sigma e^{-(\mu+\gamma)(T_R-T_{GB})} \gamma e^{-\mu(T_O-T_R)}$$

$$p(T_0) = \int_0^{T_O} dT_R \int_0^{T_R} dT_{GB} \int_0^{T_{GB}} dT_I \, e^{-\int_0^{T_I} \lambda(s)ds - (\mu+\sigma)T_I} \lambda(T_I) e^{-(\mu+\gamma+\sigma)(T_{GB}-T_I)} \sigma e^{-(\mu+\gamma)(T_R - T_{GB})} \gamma e^{-\mu(T_O - T_R)}$$

$$Risk = \frac{\int_{\omega}^{\omega+\Omega} \lambda(t)S(t)dt'}{N(0)}$$

$$\lambda(t) = ab\frac{I_M(t)}{N_H(t)}$$

$$\frac{dS_H}{dt} = -abI_M \frac{S_H}{N_H} - \mu_H S_H + r_H N_H \left(1 - \frac{N_H}{\kappa_H}\right)$$

$$\frac{dI_H}{dt} = abI_M \frac{S_H}{N_H} - (\mu_H + \alpha_H + \gamma_H) I_H$$

$$\frac{dR_H}{dt} = \gamma_H I_H - \mu_H R_H$$

$$\frac{dS_M}{dt} = p_S c_S(t) S_E - \mu_M S_M - acS_M \frac{I_H}{N_H}$$

$$\frac{dL_M}{dt} = acS_M \frac{I_H}{N_H} - \gamma_M L_M - \mu_M L_M$$

$$\frac{dI_M}{dt} = \gamma_M L_M - \mu_M I_M + p_I c_S(t) I_E$$

$$\frac{dS_E}{dt} = \left[r_M S_M + (1-g) r_M I_M\right]\left(1 - \frac{(S_E + I_E)}{\kappa_E}\right) - \mu_E S_E - p_S c_S(t) S_E$$

$$\frac{dI_E}{dt} = \left[g r_M I_M\right]\left(1 - \frac{(S_E + I_E)}{\kappa_E}\right) - \mu_E I_E - p_I c_S(t) I_E$$

$$N_H = S_H + I_H + R_H$$

$$N_M = S_M + L_M + I_M$$


Chikungunya virus
Courtesy of the National Pest Management Association; Tom Myers

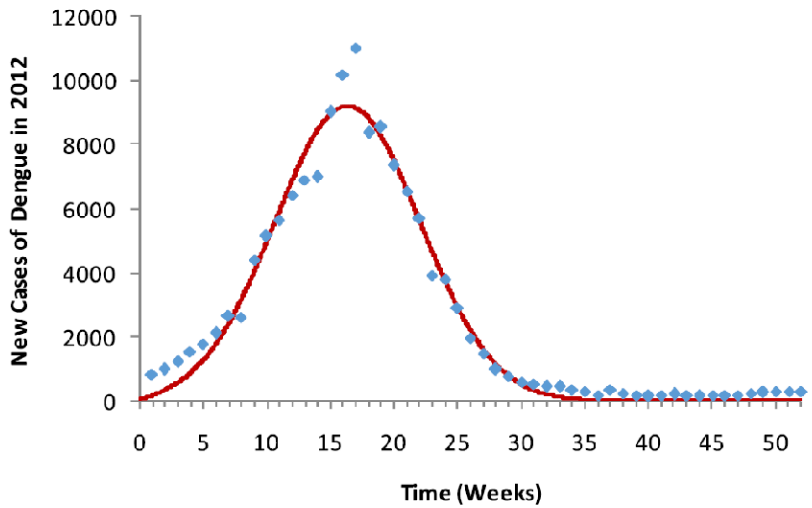
$$R_{0\text{chik}} = R_{0\text{dengue}} \frac{\gamma_{\text{dengue}}}{\gamma_{\text{chik}}} \frac{b_{\text{chik}} c_{\text{chik}}}{b_{\text{dengue}} c_{\text{dengue}}} \exp(-\mu_M(\tau_{\text{chik}} - \tau_{\text{dengue}})).$$

$$Risk = \frac{\int_{\omega}^{\omega+\Omega} \lambda(t) S(t) dt'}{N(0)}$$

$$\lambda(t) = ab \frac{I_M(t)}{N_H(t)}$$

$$Incidence = \lambda(t)S(t)$$

$$\lambda(t)S(t) = c_1 exp\left[-\frac{(t-c_2)^2}{c_3}\right]$$



$$\lambda(t)S(t) = c_1 exp\left[-\frac{(t-c_2)^2}{c_3}\right]$$

$$\frac{dS'_H}{dt} = \left(-a'b'I_M\frac{S'_H}{N_H} - \mu_H S'_H\right)\theta(t-t_0)$$

$$\frac{dI'_H}{dt} = \left(a'b'I_M\frac{S'_H}{N_H} - (\mu_H + \gamma_H + \alpha_H)I'_H\right)\theta(t-t_0)$$

$$\frac{dR'_H}{dt} = (\gamma_H I'_H - \mu_H R'_H - \sigma_H R'_H)\theta(t-t_0)$$

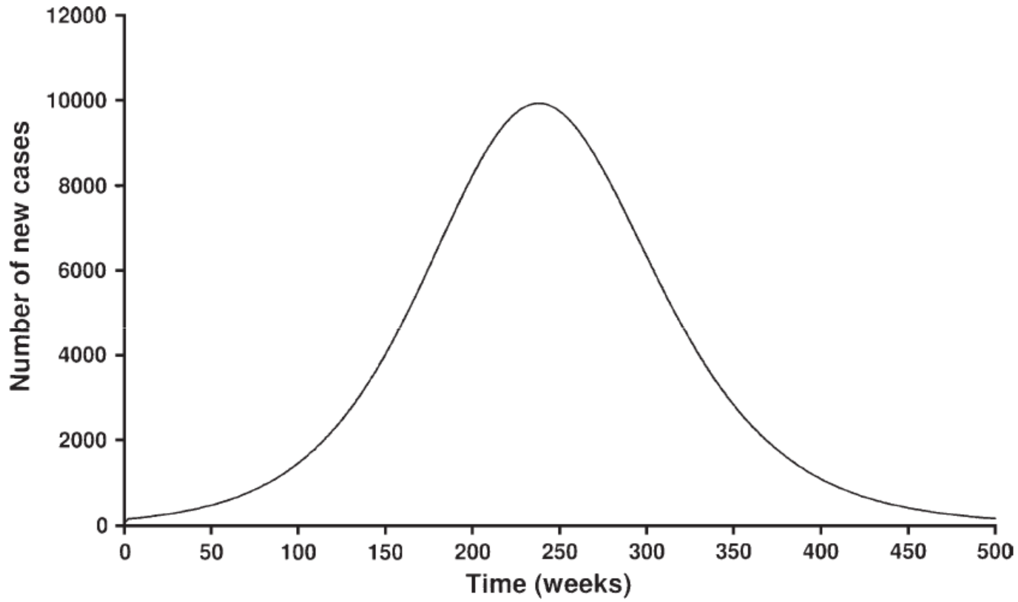


Figure 2 Number of new chikungunya cases as a function of time since the introduction of a single infective case.

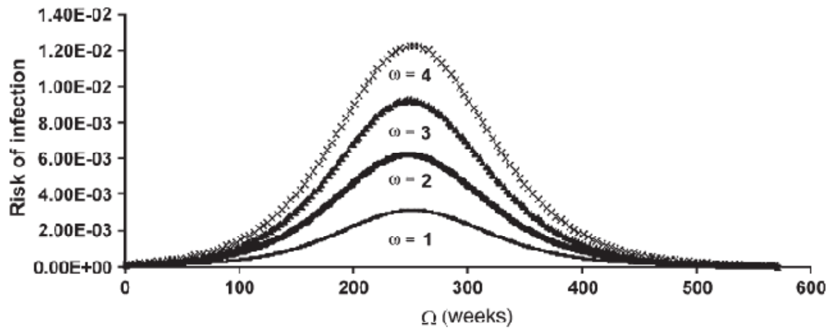


Figure 3 The risk of chikungunya infection of a traveler who arrives at week Ω and remains there for ω weeks.

DENGUE

From the 85 countries that reported the1597220dengue cases to WHO in 2012 we selected the 16 which were responsible for 95% of cases. These countries, along with the number and relative contribution to the total number of dengue cases are shown in Table 1.

Table 1. Selected 'source' countries exporting dengue cases (2012)

Country	Reported Cases	Percentage of World cases
Brazil	565510	34 %
Mexico	164947	10 %
Philippines	154945	9 %
Thailand	78063	5 %
Indonesia	74062	4 %
Viet Nam	69023	4 %
India	50222	3 %
Colombia	49361	3 %
Venezuela	49044	3 %
Sri Lanka	44456	3 %
Bolivia	42704	3 %
El Salvador	41793	2 %
Cambodia	40164	2 %
Paraguay	39063	2 %
Nicaragua	30499	2 %
Peru	29994	2 %
Costa Rica	22243	1 %
Malaysia	19029	1 %
Ecuador	16544	1 %
Honduras	15554	1 %
Total	1597220	95 %

Figure 5. Selected countries with the highest reported number of dengue cases in 2012.

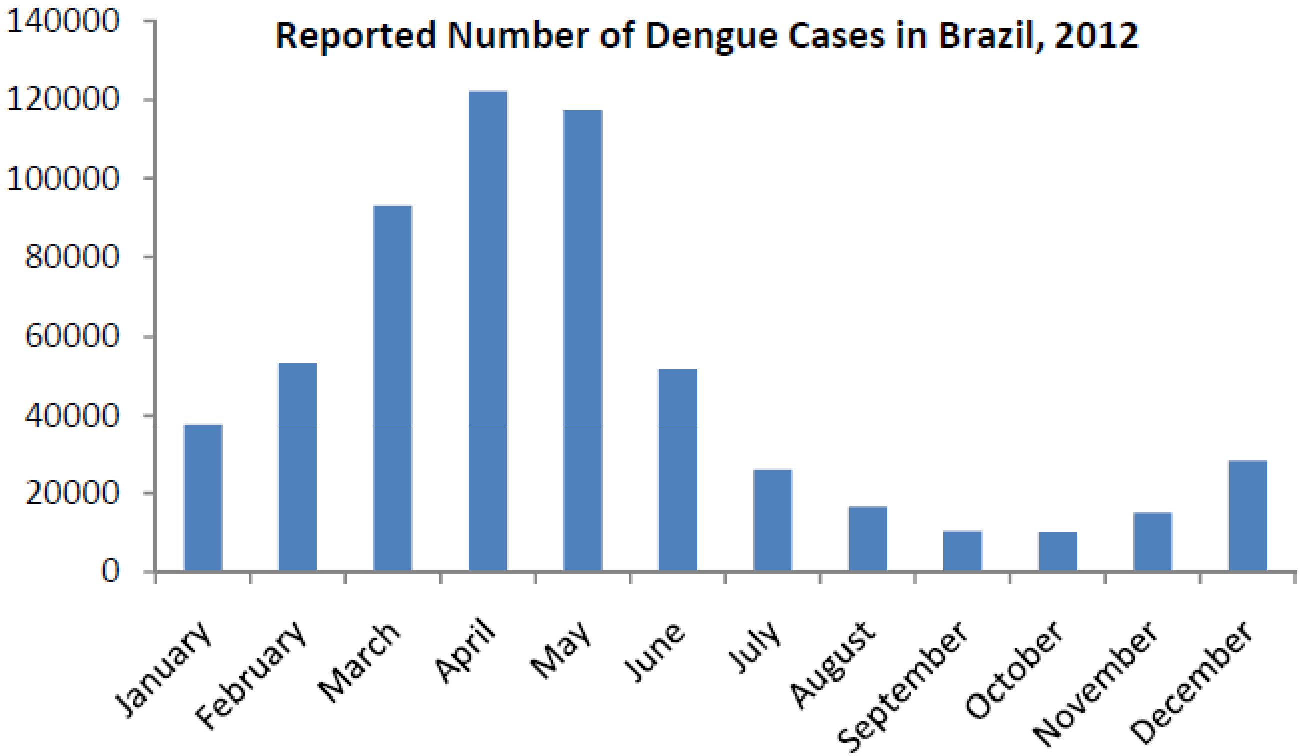


Figure 1. Seasonal distribution of reported dengue cases in Brazil in 2012.

$$\lambda(t)S(t) = c_1 exp\left[-\frac{(t-c_2)^2}{c_3}\right]F(t)$$

$$F(t) = \frac{1}{1+\exp(-c_4(t-c_5))} + rect(t)c_6$$

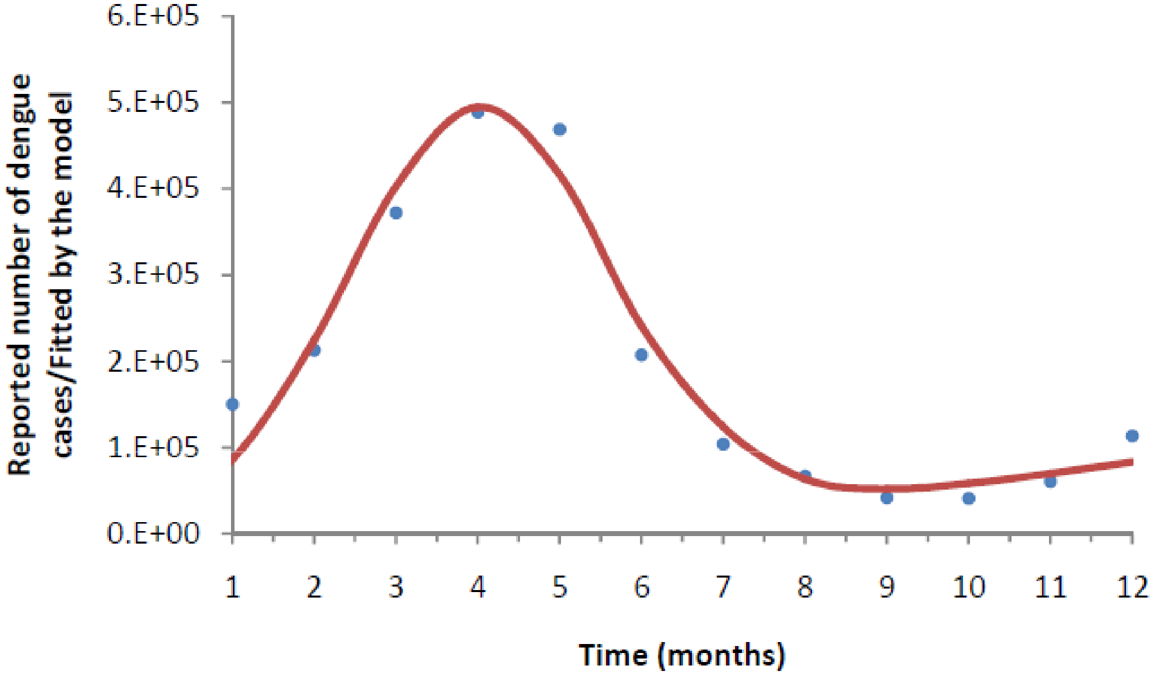


Figure 3. Fitting quality of equation (2) (line) to the officially reported number of dengue cases (dots) for Brazil in 2012.

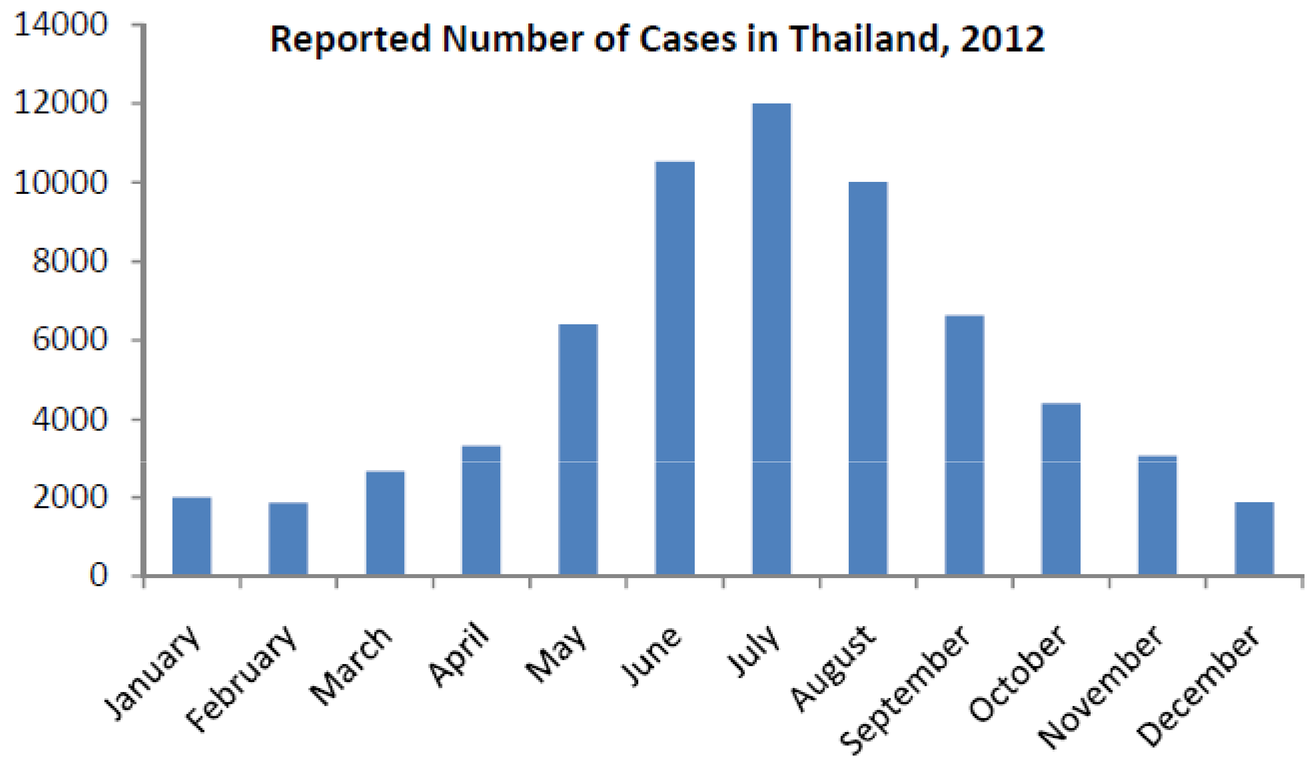


Figure 2. Seasonal distribution of reported dengue cases in Thailand in 2012.

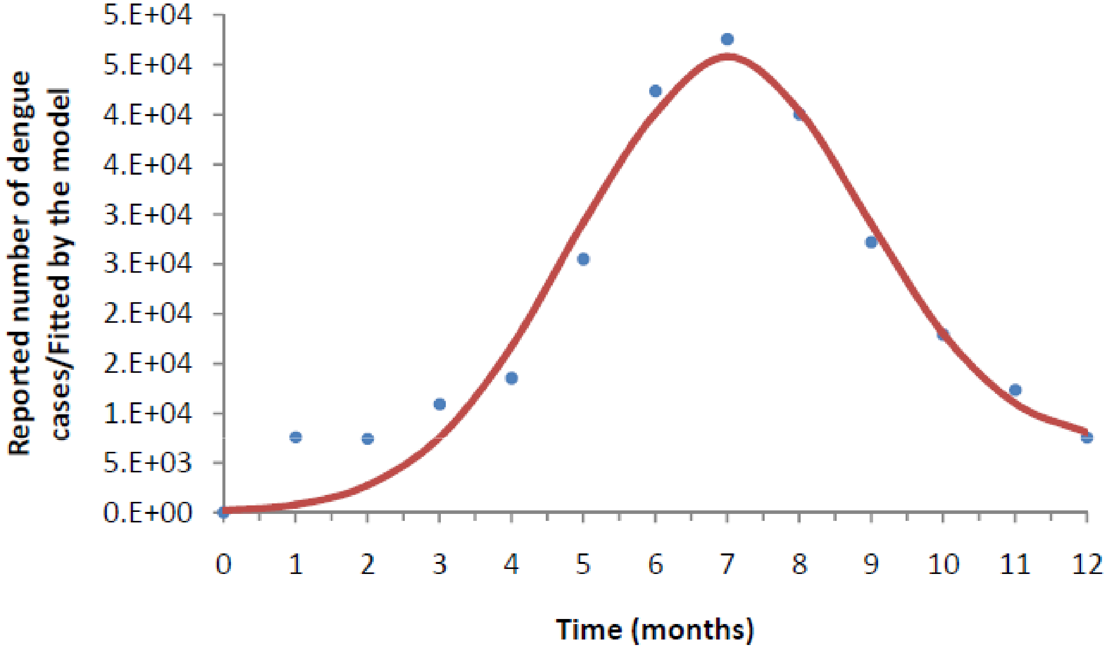
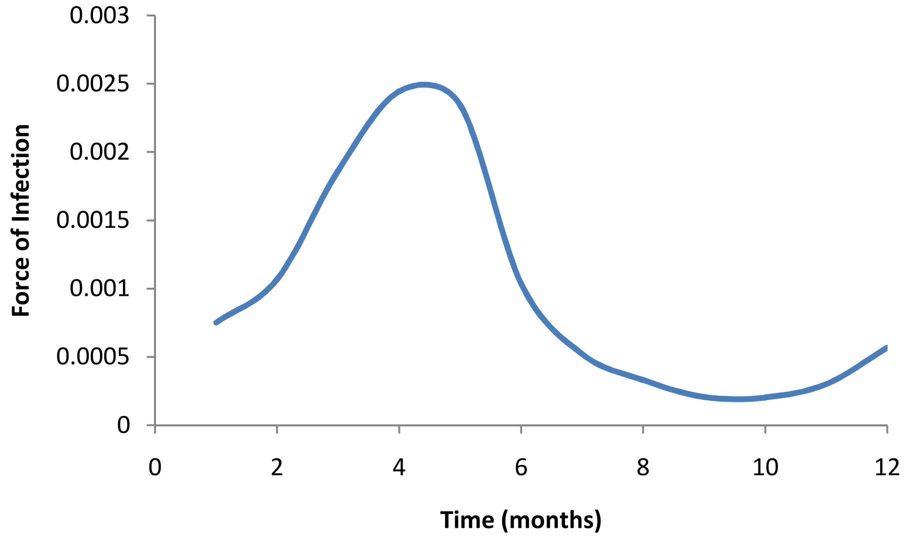
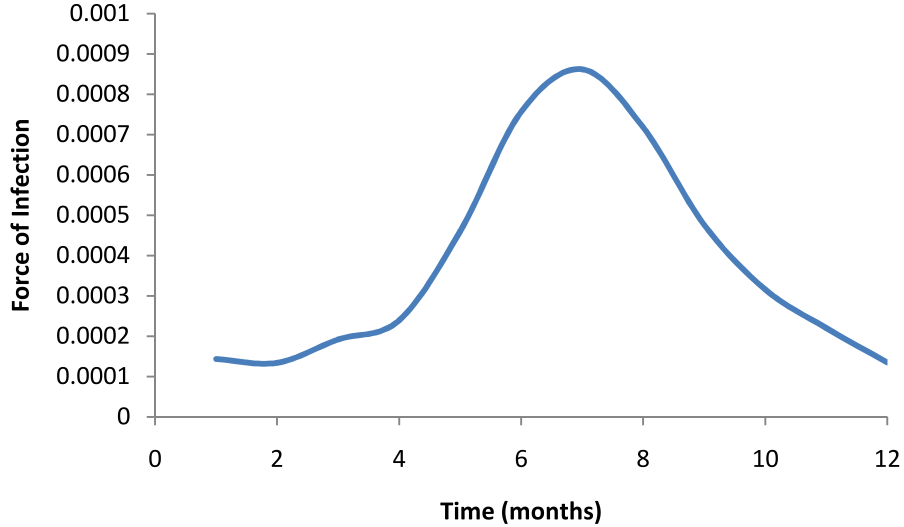


Figure 4. Fitting quality of equation (2) (line) to the officially reported number of dengue cases (dots) for Thailand in 2012.



0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Force of Infection
0
2
4
6
8
10
12
Time (months)



0.001
0.0009
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
Force of Infection
0
2
4
6
8
10
12
Time (months)

From	To	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Mexico	Albania	14	5	15	33	39	39	28	40	37	15	3	4	272
Mexico	Austria	1415	1460	2105	1683	1579	1114	2558	1681	1622	1267	1361	1413	19258
Mexico	Belgium	3007	2183	2570	3193	2540	2137	2658	2794	2114	2079	2477	2071	29823
Mexico	Bulgaria	128	69	218	77	111	157	130	187	51	75	26	42	1271
Mexico	Switzerland	5113	3787	4381	3803	3189	3624	3887	3935	3018	3146	3720	3373	44976
Mexico	Czech	470	820	959	601	521	871	982	670	1001	761	883	680	9219
Mexico	Germany	16404	13397	16582	16397	15342	12383	13561	11891	14699	12251	15450	14700	173057
Mexico	Denmark	1845	1513	1226	1141	1129	1043	1974	1822	780	491	754	1174	14892
Mexico	Spain	28400	20570	28364	28825	28291	32159	46924	36064	35595	31711	24633	29058	370594
Mexico	Finland	864	316	470	372	480	446	370	192	464	367	161	560	5062
Mexico	France	17021	18049	26937	22847	17844	17075	24487	22542	15716	14133	20445	21418	238514
Mexico	United	18210	14259	19863	14513	11689	11988	18641	17621	15317	12623	13358	13874	181956
Mexico	Greece	188	161	251	360	670	553	880	1013	673	484	267	231	5731
Mexico	Croatia	61	59	48	142	72	92	92	156	149	62	55	39	1027
Mexico	Hungary	731	640	609	559	492	534	455	499	599	335	394	389	6236
Mexico	Italy	10959	9938	12420	10622	12753	13133	19559	19912	14436	12402	10488	11293	157915
Mexico	Malta	78	75	79	62	22	21	5	22	47	18	22	8	459
Mexico	Netherlands	7190	5409	6237	5625	8508	4949	8612	7621	8303	7386	5686	5813	81339
Mexico	Norway	1319	588	848	643	732	438	767	616	434	580	436	593	7994
Mexico	Poland	563	937	665	578	578	642	592	544	719	428	458	598	7302
Mexico	Portugal	606	660	832	969	1230	1119	1143	970	979	1119	796	952	11375
Mexico	Romania	369	284	273	388	464	358	381	334	411	385	330	288	4265
Mexico	Serbia	22	13	46	40	52	65	102	66	45	54	23	27	555
Mexico	Sweden	1666	1112	885	645	696	1032	1173	790	464	493	770	1028	10754
Mexico	Slovenia	27	33	32	34	29	20	74	22	27	10	100	44	452
Mexico	Slovakia	24	2	0	0	0	0	0	0	9	0	3	0	38
Mexico	Turkey	499	497	761	1143	1202	1643	893	673	1025	1022	768	792	10918

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$$\frac{dS_H}{dt} = -\lambda S_H - \mu_H S_H$$

$$\frac{dI_H}{dt} = \lambda S_H - (\mu_H + \gamma_H + \alpha_H) I_H$$

$$Risk(t) = 1 - \exp\left[-\int_{t_1}^{t_2} \lambda(t)\, dt\right]$$

Table 2. Expected number of infected people leaving the airports of the 16 selected countries in 2012

	Brazil			Bolivia			Colombia			Venezuela		
Month	Risk	Cases	95%CI	Risk	Cases	95% CI	Risk	Cases	95%CI	Risk	Cases	95% CI
Jan	0.000482	111	1	0.000178	2	1	0.000175	9	1	0.000273	9	1
Feb	0.001482	279	2	0.000546	4	1	0.000537	19	1	0.000836	21	2
Mar	0.003152	624	3	0.001158	8	2	0.001139	43	2	0.001774	57	2
Apr	0.00465	958	4	0.001702	10	2	0.001674	60	2	0.002609	83	3
May	0.004791	1147	4	0.001736	14	2	0.001708	60	2	0.002664	90	3
Jun	0.003374	744	3	0.001229	6	2	0.001209	53	2	0.001887	67	2
Jul	0.001795	434	2	0.000652	3	1	0.000642	26	1	0.001003	41	2
Aug	0.000901	195	2	0.000326	2	1	0.000321	14	1	0.000502	23	1
Sep	0.000563	135	1	0.000204	1	1	0.000201	9	1	0.000314	11	1
Oct	0.000558	113	1	0.000202	1	1	0.000199	7	1	0.000311	9	1
Nov	0.000658	116	1	0.000238	1	1	0.000234	7	1	0.000366	11	1
Dec	0.000783	162	1	0.000284	1	1	0.00028	10	1	0.000438	17	1
Total		5018	26		55	16		316	15		440	19

	Brazil	Mexico	Philippines	Thailand	Indonesia	Viet Nam	India	Colombia	Venez	Sri Lanka	Bolivia	El Salvador	Cambodia	Paraguay	Nicaragua	Peru	Total
Albania	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Austria	157	14	10	40	2	5	1	3	3	5	0	1	2	1	1	3	246
Belgium	60	12	8	44	2	2	1	5	2	6	1	2	2	2	1	2	156
Bulgaria	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	6
Czech	34	7	2	15	1	14	1	0	1	5	0	0	1	0	0	1	83
Germany	508	110	50	352	19	47	8	35	25	72	3	13	13	11	20	23	1310
Dennm	61	10	14	93	2	8	1	2	2	8	1	2	1	1	3	4	213
Spain	535	280	27	54	3	4	2	139	203	4	34	42	3	37	38	80	1485
Finland	18	3	3	21	1	2	0	1	1	1	0	0	0	0	1	2	53
France	802	160	34	227	20	54	6	36	37	49	3	23	86	20	18	54	1629
Greece	33	5	6	10	1	0	0	1	3	3	0	0	0	0	0	0	64
Switzer	227	29	16	108	7	10	3	12	9	41	1	5	5	4	5	12	495
UK	574	122	141	357	18	26	28	31	23	206	3	8	17	7	10	29	1600
Croatia	11	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	16
Hungary	22	4	1	7	0	1	0	0	1	1	0	0	0	0	0	1	38
Italy	798	123	70	116	9	7	6	32	75	87	5	27	5	24	15	40	1439
Malta	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Nether	153	59	30	99	25	11	2	7	8	11	1	4	6	3	12	11	444
Norway	42	5	18	62	1	8	1	1	1	16	0	1	1	1	4	2	165
Poland	32	5	2	9	0	5	1	1	1	1	0	0	0	0	0	1	58
Portugal	789	8	2	8	1	1	0	4	38	1	0	1	0	1	1	3	859
Romania	12	3	2	3	0	0	0	1	1	1	0	0	0	0	0	0	24
Serbia	2	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	6
Sweden	51	6	10	89	1	4	1	3	1	7	2	4	2	4	3	4	193
Slovenia	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Slovakia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Turkey	87	8	11	25	5	1	2	2	5	4	0	1	0	1	0	1	154
Total	5018 ± 26	976 ± 15	461 ± 17	1744 ± 15	122 ± 7	212 ± 12	66 ± 3	316 ± 15	440 ± 19	530 ± 19	55 ± 16	136 ± 40	145 ± 25	118 ± 37	133 ± 35	274 ± 15	10746 ± 316

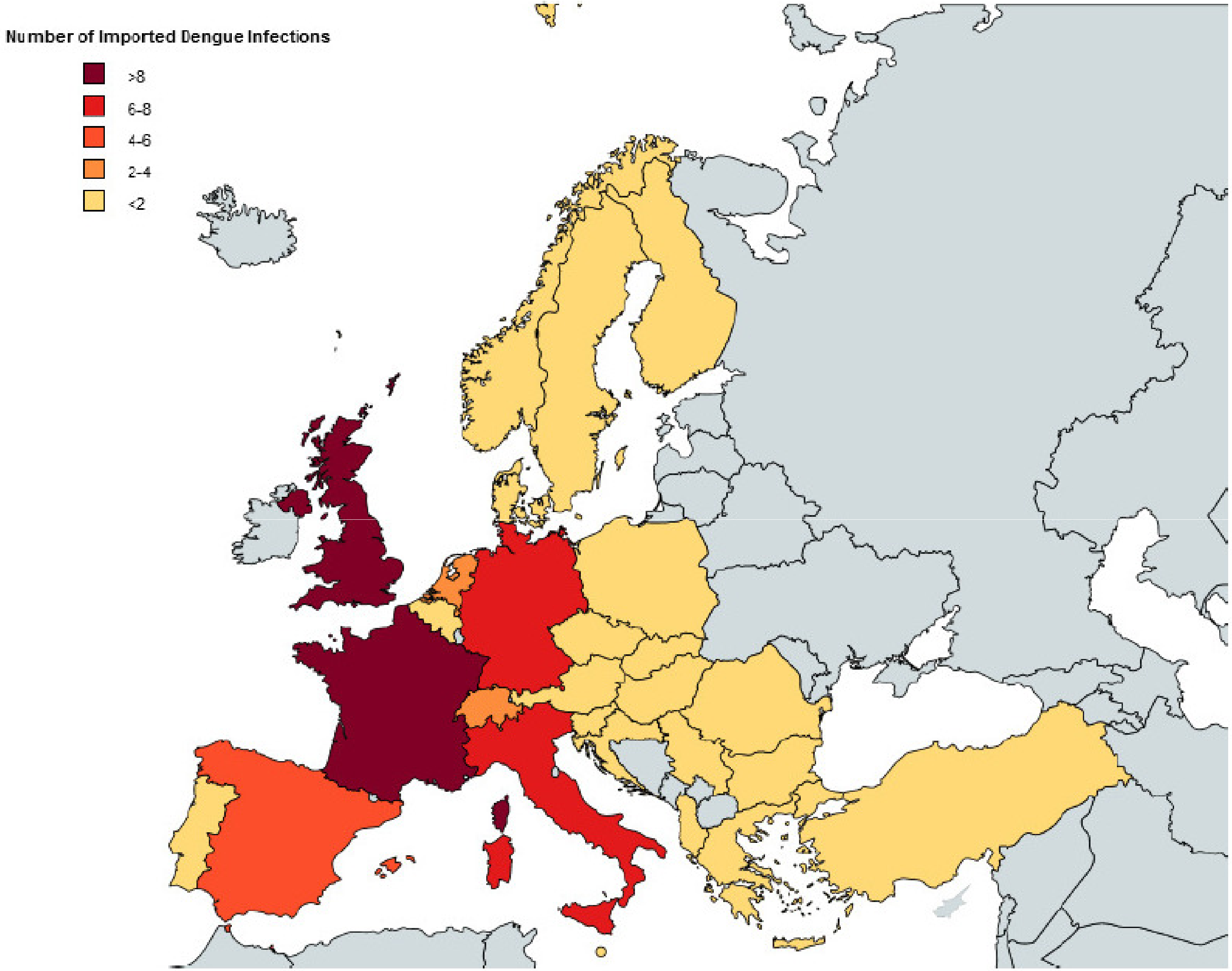
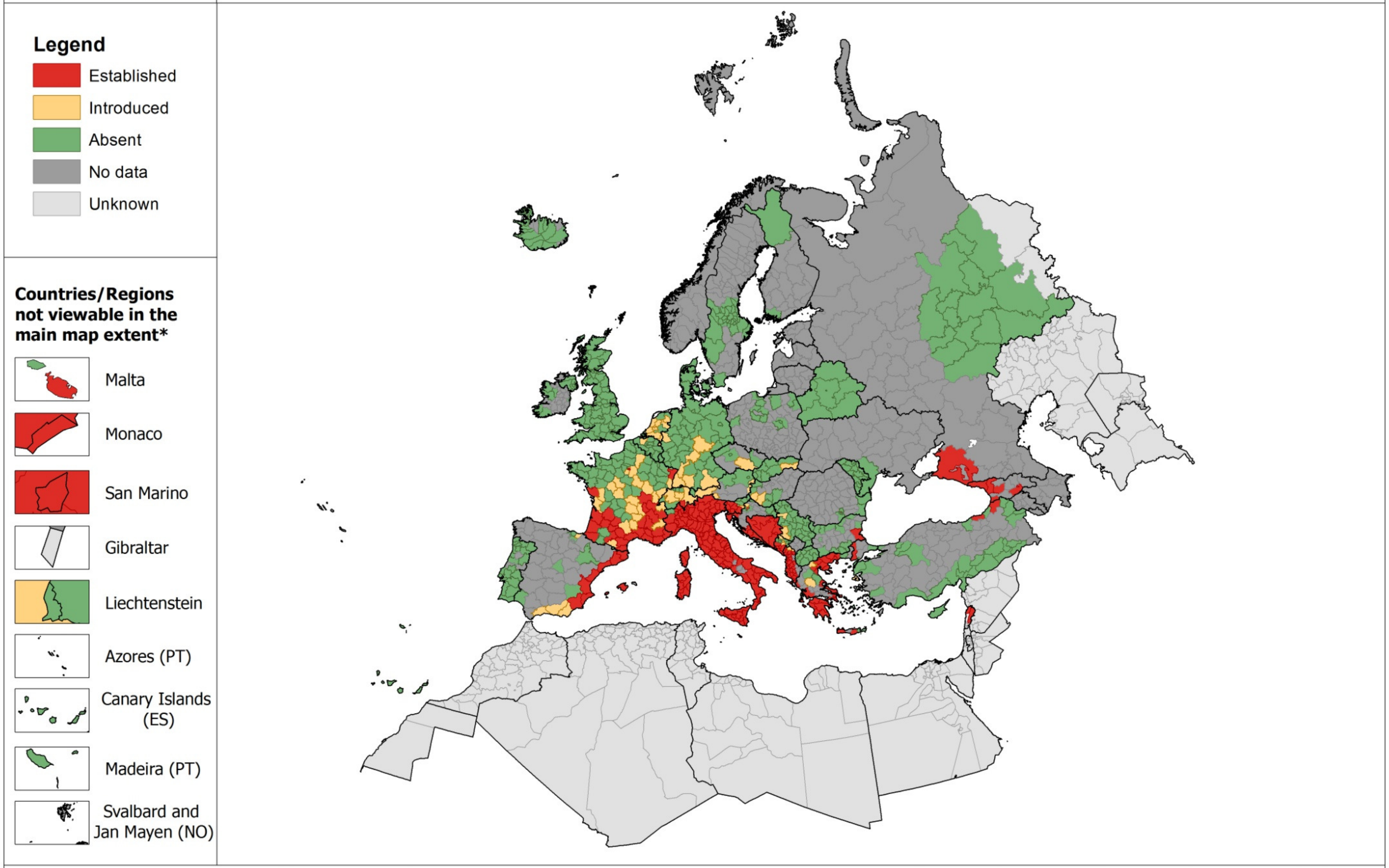


Figure 6. Expected number of dengue cases exported to European countries by the 16 selected dengue endemic countries in August 2012.

Aedes albopictus - current known distribution: July 2016



ECDC and EFSA. Map produced on 2 Aug 2016. Data presented in this map is collected through the VectorNet project. The maps are validated by designated external experts prior to publication. Please note that the data do not represent the official view or position of the countries. * Countries/Regions are displayed at different scales to facilitate their visualisation. Administrative boundaries: ©EuroGeographics; ©UN-FAO; ©Turkstat.

Table S2a

T (°C)	n (day)				μ_M (day^{-1})				a(day^{-1})				m				b_m				b_h				VC (day^{-1})			
	mean	n-95%CI	n+95%CI	sd	mean	μ_M- 95%CI	μ_M+95%CI	sd	mean	a-95%CI	a+95%CI	sd	mean	m-95%CI	m+95%CI	sd	mean	b_m-95%CI	b_m+95%CI	sd	mean	b_h-95%CI	b_h+95%CI	sd	mean	VC-95%CI	VC+95%CI	sd
10.0	54.41	49.07	59.95	2.78	0.092	0.083	0.101	0.0046	0.14	0.12	0.15	0.007	0.42	0.38	0.47	0.021	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.000
12.0	43.43	38.93	47.38	2.16	0.058	0.052	0.064	0.0028	0.15	0.13	0.16	0.007	0.67	0.60	0.73	0.034	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.000
14.0	34.84	31.32	38.28	1.77	0.042	0.038	0.046	0.0020	0.15	0.14	0.17	0.008	0.94	0.84	1.03	0.047	0.12	0.10	0.13	0.006	0.11	0.10	0.12	0.005	0.00	0.00	0.00	0.000
16.0	28.07	25.28	30.77	1.39	0.036	0.032	0.039	0.0018	0.16	0.15	0.18	0.008	1.09	0.99	1.18	0.051	0.26	0.24	0.29	0.013	0.25	0.23	0.28	0.013	0.02	0.01	0.03	0.003
18.0	22.82	20.67	24.92	1.11	0.035	0.032	0.039	0.0018	0.17	0.15	0.19	0.008	1.10	1.00	1.21	0.055	0.41	0.37	0.45	0.020	0.41	0.37	0.45	0.020	0.07	0.05	0.09	0.011
20.0	18.74	16.94	20.57	0.94	0.036	0.032	0.040	0.0019	0.18	0.16	0.20	0.009	1.08	0.97	1.19	0.054	0.55	0.50	0.61	0.027	0.57	0.52	0.62	0.028	0.15	0.11	0.21	0.025
22.0	15.53	14.05	16.98	0.76	0.036	0.033	0.040	0.0017	0.19	0.17	0.21	0.009	1.08	0.98	1.19	0.053	0.70	0.63	0.77	0.036	0.72	0.66	0.80	0.035	0.31	0.22	0.41	0.049
24.0	13.01	11.75	14.23	0.64	0.034	0.031	0.037	0.0017	0.20	0.18	0.22	0.010	1.15	1.04	1.27	0.057	0.85	0.76	0.93	0.043	0.86	0.77	0.94	0.043	0.62	0.46	0.82	0.092
25.0	11.97	10.92	13.13	0.58	0.032	0.029	0.035	0.0016	0.20	0.18	0.22	0.010	1.22	1.10	1.35	0.061	0.92	0.83	1.01	0.046	0.91	0.82	0.99	0.046	0.88	0.65	1.16	0.131
26.0	11.03	10.00	12.09	0.55	0.030	0.027	0.033	0.0016	0.21	0.19	0.22	0.010	1.30	1.17	1.42	0.066	0.99	0.90	1.09	0.050	0.95	0.85	1.04	0.048	1.23	0.92	1.63	0.180
27.0	10.20	9.19	11.17	0.50	0.028	0.025	0.031	0.0014	0.21	0.19	0.23	0.011	1.38	1.25	1.52	0.068	1.00	0.90	1.10	0.050	0.97	0.88	1.06	0.048	1.59	1.15	2.08	0.236
28.0	9.52	8.62	10.43	0.49	0.027	0.024	0.029	0.0013	0.21	0.19	0.23	0.011	1.47	1.32	1.61	0.073	1.00	0.90	1.10	0.052	0.97	0.88	1.06	0.048	1.91	1.41	2.51	0.294
29.0	8.88	8.03	9.77	0.45	0.026	0.023	0.028	0.0013	0.22	0.20	0.24	0.011	1.50	1.34	1.66	0.077	1.00	0.91	1.10	0.049	0.94	0.84	1.03	0.048	2.07	1.52	2.70	0.311
30.0	8.31	7.52	9.10	0.41	0.027	0.024	0.030	0.0013	0.22	0.20	0.24	0.011	1.45	1.32	1.59	0.073	1.00	0.90	1.10	0.052	0.87	0.79	0.95	0.043	1.87	1.38	2.43	0.276
30.7	7.94	7.20	8.75	0.40	0.029	0.026	0.032	0.0015	0.23	0.20	0.25	0.011	1.36	1.23	1.49	0.066	1.00	0.90	1.09	0.050	0.78	0.71	0.86	0.039	1.52	1.14	1.98	0.214
31.4	7.62	6.90	8.37	0.38	0.032	0.029	0.035	0.0016	0.23	0.21	0.25	0.011	1.23	1.10	1.34	0.061	1.00	0.90	1.09	0.049	0.65	0.58	0.71	0.031	1.02	0.76	1.34	0.150
32.0	7.38	6.65	8.09	0.36	0.036	0.032	0.039	0.0018	0.23	0.21	0.25	0.012	1.09	0.98	1.20	0.056	1.00	0.90	1.10	0.052	0.45	0.40	0.49	0.022	0.57	0.42	0.73	0.083
32.3	7.24	6.53	7.95	0.36	0.038	0.034	0.042	0.0019	0.23	0.21	0.25	0.012	1.02	0.92	1.12	0.050	1.00	0.89	1.10	0.053	0.27	0.24	0.30	0.014	0.30	0.22	0.39	0.044
32.5	7.18	6.49	7.85	0.35	0.040	0.036	0.044	0.0020	0.23	0.21	0.26	0.012	0.98	0.88	1.08	0.052	1.00	0.90	1.10	0.051	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.000

Table S2b

T (°C)	n (day)				μ_M (day^{-1})				a(day^{-1})				m				b_m				b_h				VC (day^{-1})			
	mean	n-95%CI	n+95%CI	sd	mean	μ_M- 95%CI	μ_M+95%CI	sd	mean	a-95%CI	a+95%CI	sd	mean	m-95%CI	m+95%CI	sd	mean	b_m-95%CI	b_m+95%CI	sd	mean	b_h-95%CI	b_h+95%CI	sd	mean	VC-95%CI	VC+95%CI	sd
10.0	54.41	49.07	59.95	2.78	0.026	0.023	0.028	0.0013	0.15	0.13	0.16	0.007	1.32	1.19	1.45	0.067	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.000
12.0	43.43	38.93	47.38	2.16	0.023	0.021	0.025	0.0011	0.10	0.09	0.10	0.005	1.50	1.35	1.64	0.075	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.000
14.0	34.84	31.32	38.28	1.77	0.024	0.022	0.026	0.0012	0.07	0.06	0.08	0.004	1.43	1.28	1.57	0.071	0.12	0.10	0.13	0.006	0.08	0.07	0.08	0.004	0.00	0.00	0.00	0.000
16.0	28.07	25.28	30.77	1.39	0.027	0.025	0.030	0.0013	0.07	0.06	0.08	0.003	1.27	1.15	1.38	0.060	0.26	0.24	0.29	0.013	0.18	0.16	0.19	0.009	0.00	0.00	0.01	0.001
18.0	22.82	20.67	24.92	1.11	0.031	0.028	0.034	0.0015	0.08	0.07	0.09	0.004	1.13	1.02	1.23	0.056	0.41	0.37	0.45	0.020	0.29	0.26	0.31	0.014	0.01	0.01	0.02	0.002
20.0	18.74	16.94	20.57	0.94	0.033	0.030	0.036	0.0017	0.11	0.10	0.12	0.005	1.04	0.94	1.14	0.052	0.55	0.50	0.61	0.027	0.40	0.36	0.44	0.020	0.05	0.03	0.06	0.007
22.0	15.53	14.05	16.98	0.76	0.034	0.031	0.037	0.0016	0.14	0.13	0.16	0.007	1.01	0.91	1.11	0.050	0.70	0.63	0.77	0.036	0.50	0.46	0.56	0.025	0.13	0.09	0.17	0.020
24.0	13.01	11.75	14.23	0.64	0.033	0.030	0.037	0.0016	0.18	0.16	0.20	0.009	1.03	0.92	1.13	0.051	0.85	0.76	0.93	0.043	0.60	0.54	0.66	0.030	0.33	0.24	0.43	0.049
25.0	11.97	10.92	13.13	0.58	0.033	0.030	0.036	0.0016	0.20	0.18	0.22	0.010	1.05	0.95	1.16	0.053	0.92	0.83	1.01	0.046	0.64	0.57	0.69	0.032	0.50	0.37	0.65	0.074
26.0	11.03	10.00	12.09	0.55	0.032	0.029	0.035	0.0016	0.21	0.19	0.23	0.010	1.08	0.98	1.18	0.055	0.99	0.90	1.09	0.050	0.66	0.60	0.73	0.034	0.72	0.54	0.96	0.105
27.0	10.20	9.19	11.17	0.50	0.031	0.028	0.034	0.0015	0.23	0.21	0.25	0.012	1.11	1.01	1.22	0.055	1.00	0.90	1.10	0.050	0.68	0.61	0.74	0.034	0.93	0.68	1.23	0.140
28.2	9.39	8.50	10.29	0.48	0.030	0.027	0.033	0.0015	0.24	0.22	0.26	0.012	1.15	1.04	1.26	0.057	1.00	0.90	1.10	0.052	0.68	0.61	0.74	0.034	1.16	0.86	1.52	0.179
29.3	8.71	7.87	9.57	0.44	0.029	0.026	0.032	0.0015	0.25	0.23	0.27	0.012	1.16	1.04	1.29	0.060	1.00	0.91	1.10	0.049	0.65	0.58	0.71	0.033	1.25	0.92	1.63	0.189
30.2	8.20	7.43	8.99	0.40	0.030	0.027	0.033	0.0015	0.25	0.23	0.28	0.012	1.15	1.05	1.27	0.058	1.00	0.90	1.10	0.052	0.59	0.54	0.65	0.030	1.17	0.86	1.53	0.174
31.0	7.80	7.07	8.60	0.40	0.031	0.028	0.034	0.0016	0.26	0.23	0.28	0.013	1.12	1.02	1.23	0.054	1.00	0.90	1.09	0.050	0.51	0.46	0.56	0.025	0.97	0.73	1.26	0.137
31.5	7.58	6.86	8.32	0.38	0.032	0.028	0.035	0.0016	0.25	0.23	0.28	0.013	1.09	0.98	1.19	0.054	1.00	0.90	1.09	0.049	0.43	0.39	0.48	0.021	0.76	0.56	0.99	0.111
32.0	7.38	6.65	8.09	0.36	0.033	0.030	0.036	0.0016	0.25	0.23	0.27	0.013	1.05	0.94	1.15	0.054	1.00	0.90	1.10	0.052	0.31	0.28	0.34	0.015	0.50	0.37	0.64	0.073
32.3	7.24	6.53	7.95	0.36	0.034	0.030	0.037	0.0017	0.25	0.22	0.27	0.012	1.02	0.92	1.11	0.050	1.00	0.89	1.10	0.053	0.19	0.17	0.21	0.010	0.27	0.21	0.36	0.040
32.5	7.18	6.49	7.85	0.35	0.034	0.031	0.038	0.0018	0.25	0.22	0.27	0.012	1.00	0.90	1.10	0.053	1.00	0.90	1.10	0.051	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.000

Table S2. Temperature dependent *VC* and its six vector parameters with 95% CI using *Monte Carlo* simulation for (a) *Ae. aegypti* (b) *Ae. albopictus*. The 95% Credibility Intervals and mean were estimated for each temperature ranging from 10 to 32.5. Each vector parameter was varied by σ = 5% from its mean using normal random number generator. The total number of runs was 1000.

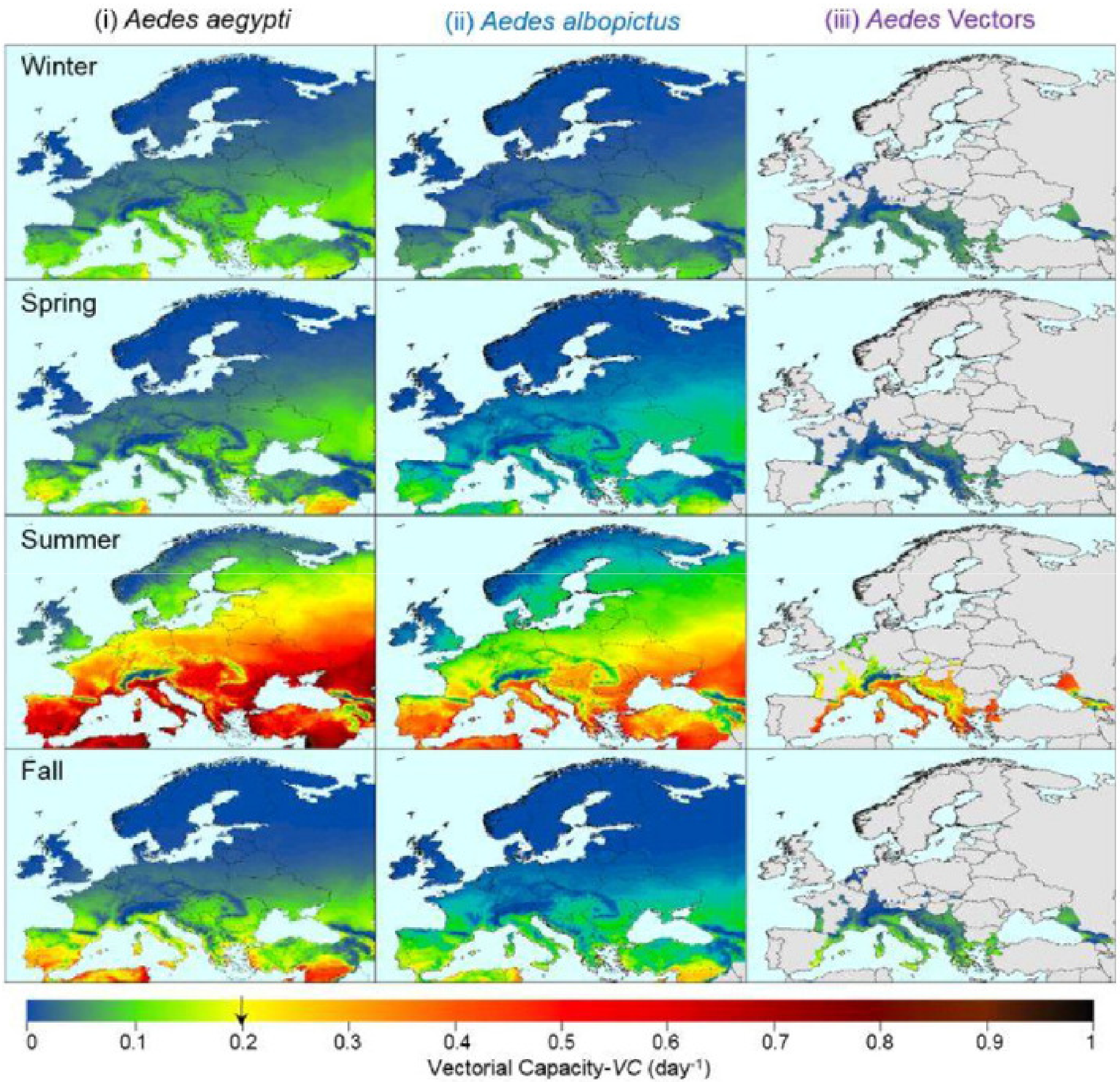


Fig. 1. Season stratified maps of *VC* for Europe for *Ae. aegypti* (i), *Ae. albopictus* (ii), and in those areas having recently established and/or introduced *Aedes* vectors (iii) (European Centre for Disease Prevention and Control (ECDC), 2015; Wilder-Smith et al., 2014b). *VC* was calculated for each day of the period (Jan. 1, 2006–Dec. 30, 2015) and then seasonally aggregated over the decade. Winter: December–February; Spring: March–May; Summer: June–August; Autumn: September–November. DTR was included and $m_{max} = 1.5$. E-OBS 12.0 daily gridded ($0.25 \times 0.25°$) temperature datasets were used (Haylock et al., 2008). The gray colored areas in this figure (iii) are those having unknown *Aedes* activity or for which survey information

$$I_H(t) = I_H(0)e^{-(\mu_H + \gamma_H)t}$$

$$I_H(t) = I_H(0)e^{-(\mu_H + \gamma_H)t}$$

$$N_M(t) = N_M(0)e^{-\mu_M t}$$

$$I_H(t) = I_H(0)e^{-(\mu_H + \gamma_H)t}$$

$$N_M(t) = N_M(0)e^{-\mu_M t}$$

$$\frac{dI_M(t)}{dt} = acN_M(0)e^{-\mu_M t}\frac{I_H(0)e^{-(\mu_H + \gamma_H)t}}{N_H} - \mu_M I_M(t)$$

$$I_H(t) = I_H(0)e^{-(\mu_H+\gamma_H)t}$$

$$N_M(t) = N_M(0)e^{-\mu_M t}$$

$$\frac{dI_M(t)}{dt} = acN_M(0)e^{-\mu_M t}\frac{I_H(0)e^{-(\mu_H+\gamma_H)t}}{N_H} - \mu_M I_M(t)$$

$$I_M(t) = \frac{N_M(0)I_H(0)}{N_H}\frac{ac}{(\mu_H+\gamma_H)}\left[1 - e^{-(\mu_H+\gamma_H)t}\right]e^{-\mu_M t}$$

$$I_H(t) = I_H(0)e^{-(\mu_H + \gamma_H)t}$$

$$N_M(t) = N_M(0)e^{-\mu_M t}$$

$$\frac{dI_M(t)}{dt} = acN_M(0)e^{-\mu_M t}\frac{I_H(0)e^{-(\mu_H + \gamma_H)t}}{N_H} - \mu_M I_M(t)$$

$$I_M(t) = \frac{N_M(0)I_H(0)}{N_H}\frac{ac}{(\mu_H + \gamma_H)}\left[1 - e^{-(\mu_H + \gamma_H)t}\right]e^{-\mu_M t}$$

$$I_M(t') = \frac{N_M(0)I_H(0)}{N_H}\frac{ac}{(\mu_H + \gamma_H)}\left[1 - e^{-(\mu_H + \gamma_H)(t'+\tau)}\right]e^{-\mu_M(t'+\tau)}$$

$$I_H(t) = I_H(0)e^{-(\mu_H+\gamma_H)t}$$

$$N_M(t) = N_M(0)e^{-\mu_M t}$$

$$\frac{dI_M(t)}{dt} = acN_M(0)e^{-\mu_M t}\frac{I_H(0)e^{-(\mu_H+\gamma_H)t}}{N_H} - \mu_M I_M(t)$$

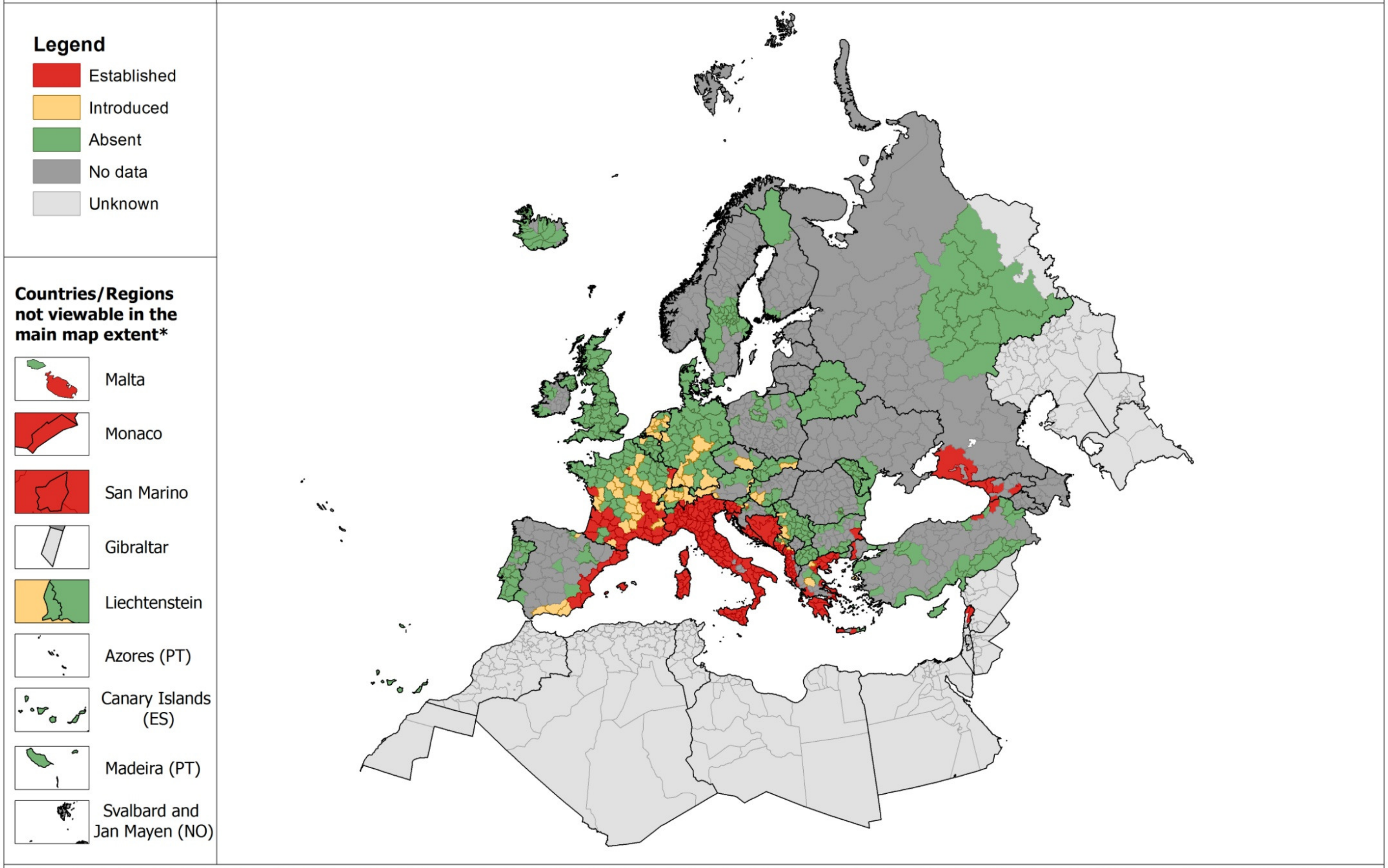
$$I_M(t) = \frac{N_M(0)I_H(0)}{N_H}\frac{ac}{(\mu_H+\gamma_H)}\left[1-e^{-(\mu_H+\gamma_H)t}\right]e^{-\mu_M t}$$

$$I_M(t') = \frac{N_M(0)I_H(0)}{N_H}\frac{ac}{(\mu_H+\gamma_H)}\left[1-e^{-(\mu_H+\gamma_H)(t'+\tau)}\right]e^{-\mu_M(t'+\tau)}$$

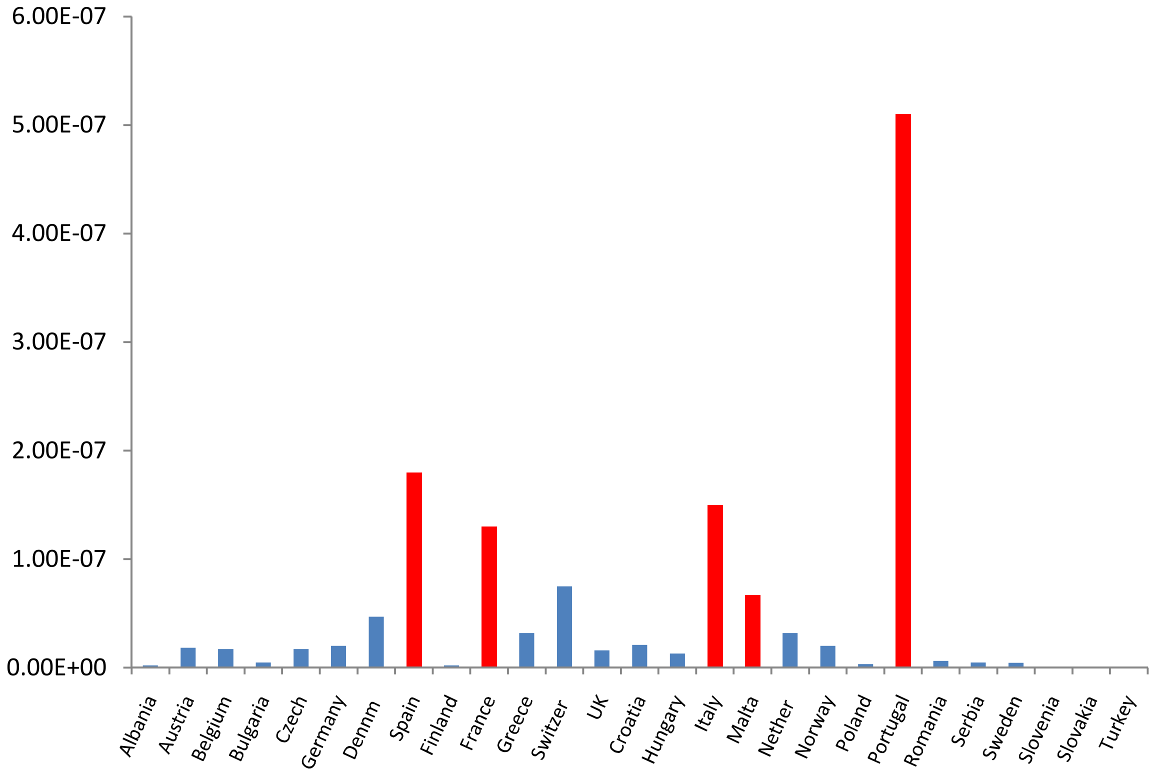
$$T = \frac{\exp(-\mu_M\tau)}{\mu_M}$$

Table 4. Parameters used to calculate the risk (from Helmerson et al., 2016)							
T (°C)	τ	μ_M	*a*	*m*	*c*	*b*	$t = \frac{e^{-\mu_M \tau}}{\mu_M}$
10	54.41	0.026	0.15	1.32	0	0	9.34647
12	43.43	0.023	0.1	1.5	0	0	16.01252
14	34.84	0.024	0.07	1.43	0.12	0.08	18.05714
16	28.07	0.027	0.07	1.27	0.26	0.18	17.35756
15	22.82	0.031	0.08	1.13	0.41	0.29	15.90046
20	18.74	0.033	0.11	1.04	0.55	0.4	16.32712
22	15.53	0.034	0.14	1.01	0.7	0.5	17.34622
24	13.01	0.033	0.18	1.03	0.85	0.6	19.72561
25	11.97	0.033	0.2	1.05	0.92	0.64	20.41434
26	11.03	0.032	0.21	1.08	0.99	0.66	21.95642
27	10.2	0.031	0.22	1.11	1	0.68	23.51334
28	9.39	0.03	0.25	1.15	1	0.68	25.15
29	8.71	0.029	0.23	1.16	1	0.65	26.78573
30	8.2	0.03	0.23	1.15	1	0.59	26.06407
30.7	7.8	0.031	0.23	1.12	1	0.51	25.32946
31.4	7.58	0.032	0.23	1.09	1	0.43	24.51927
32	7.38	0.033	0.23	1.05	1	0.31	23.75297
32.3	7.24	0.034	0.22	1.02	1	0.19	22.99403
32.5	7.18	0.034	0.22	1	1	0	23.04099

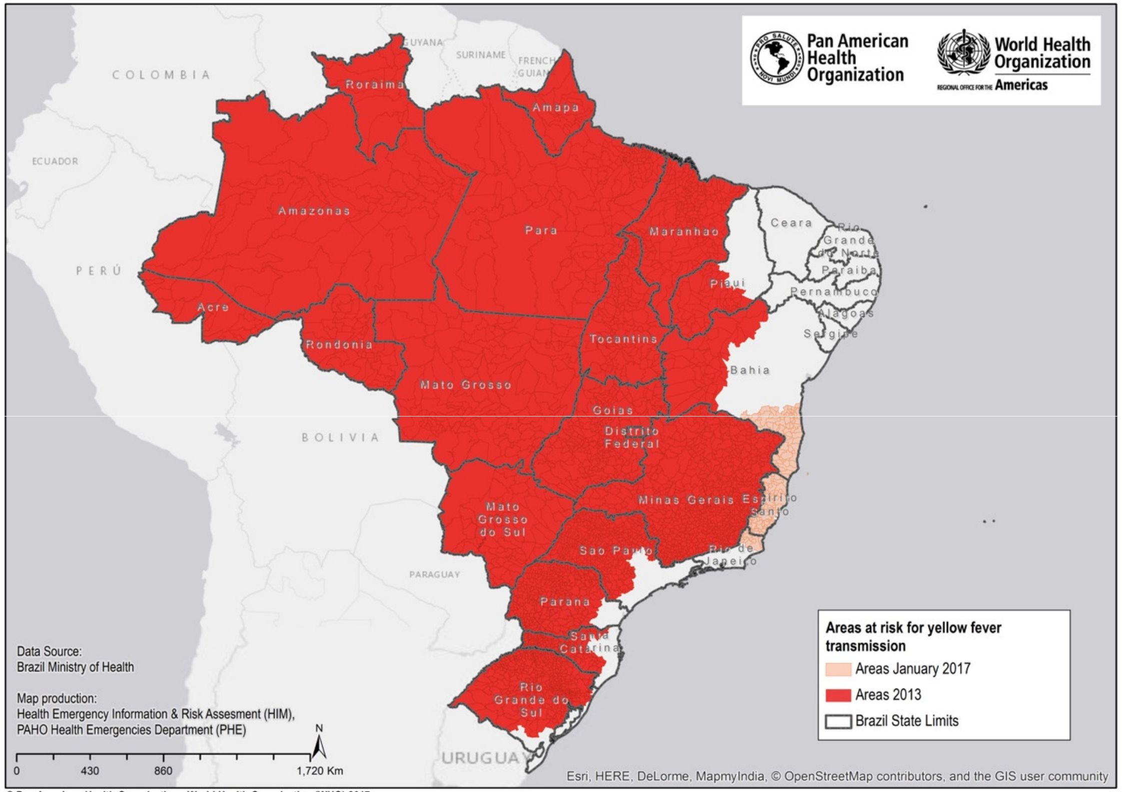
Aedes albopictus - current known distribution: July 2016



ECDC and EFSA. Map produced on 2 Aug 2016. Data presented in this map is collected through the VectorNet project. The maps are validated by designated external experts prior to publication. Please note that the data do not represent the official view or position of the countries. * Countries/Regions are displayed at different scales to facilitate their visualisation. Administrative boundaries: ©EuroGeographics; ©UN-FAO; ©Turkstat.


6.00E-07
5.00E-07
4.00E-07
3.00E-07
2.00E-07
1.00E-07
0.00E+00
Albania
Austria
Belgium
Bulgaria
Czech
Germany
Denmm
Spain
Finland
France
Greece
Switzer
UK
Croatia
Hungary
Italy
Malta
Nether
Norway
Poland
Portugal
Romania
Serbia
Sweden
Slovenia
Slovakia
Turkey


YELLOW
FEVER


Pan American Health Organization
World Health Organization
REGIONAL OFFICE FOR THE Americas
COLOMBIA
SURINAME
ECUADOR
PERÚ
BOLIVIA
PARAGUAY
URUGUAY
Roraima
Amapa
Amazonas
Para
Maranhao
Ceara
Rio Grande do Norte
Paraiba
Pernambuco
Alagoas
Sergipe
Piaui
Acre
Rondonia
Tocantins
Bahia
Mato Grosso
Goias
Distrito Federal
Minas Gerais
Espirito Santo
Mato Grosso do Sul
Sao Paulo
Rio de Janeiro
Parana
Santa Catarina
Rio Grande do Sul
Areas at risk for yellow fever transmission
Areas January 2017
Areas 2013
Brazil State Limits
Data Source:
Brazil Ministry of Health
Map production:
Health Emergency Information & Risk Assesment (HIM),
PAHO Health Emergencies Department (PHE)
N
0 430 860 1,720 Km
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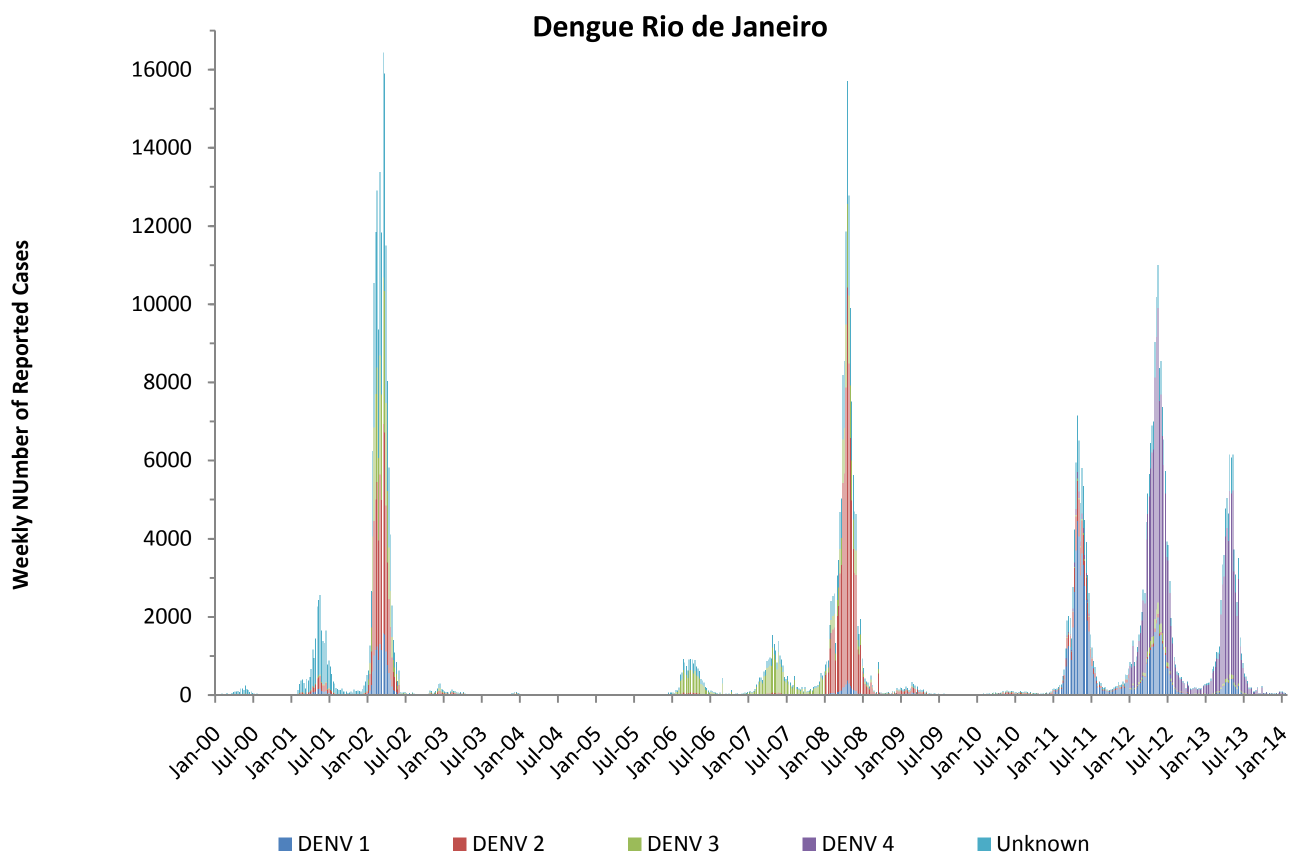
Dengue Rio de Janeiro
Weekly NUmber of Reported Cases
16000
14000
12000
10000
8000
6000
4000
2000
0
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
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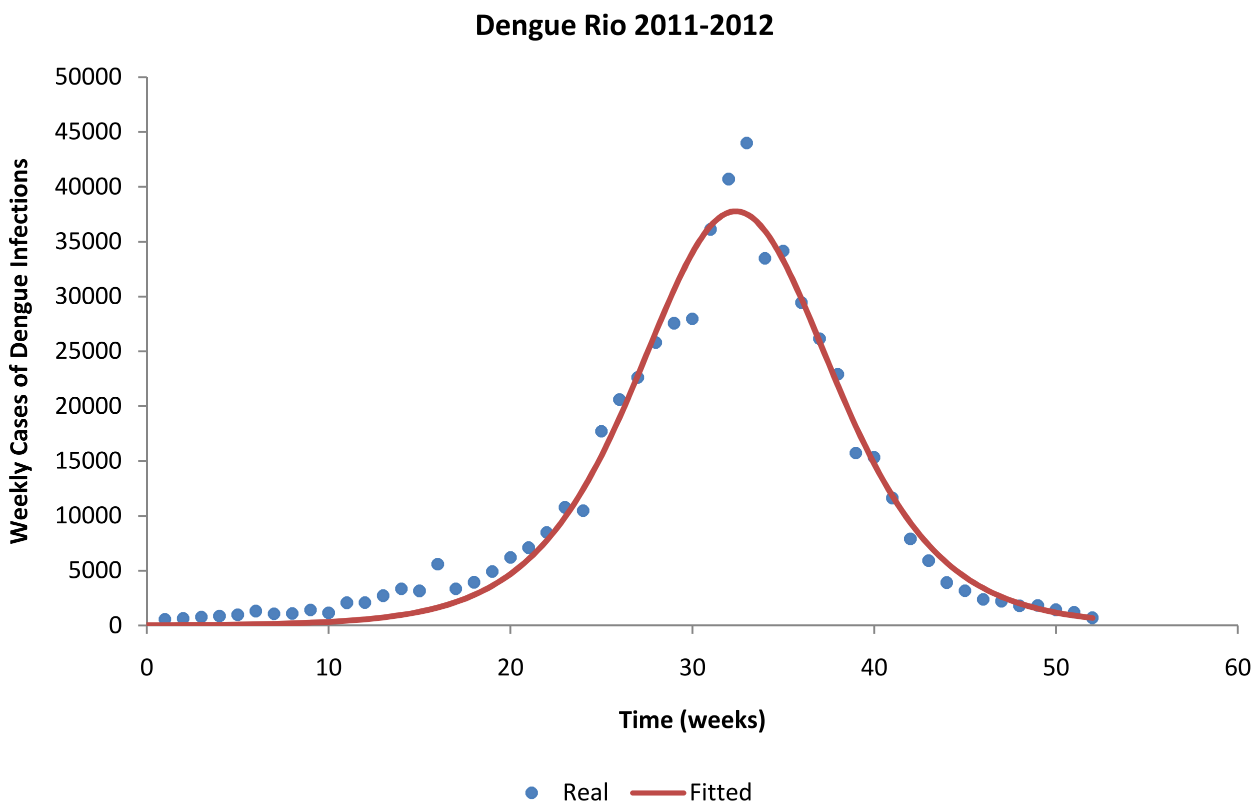
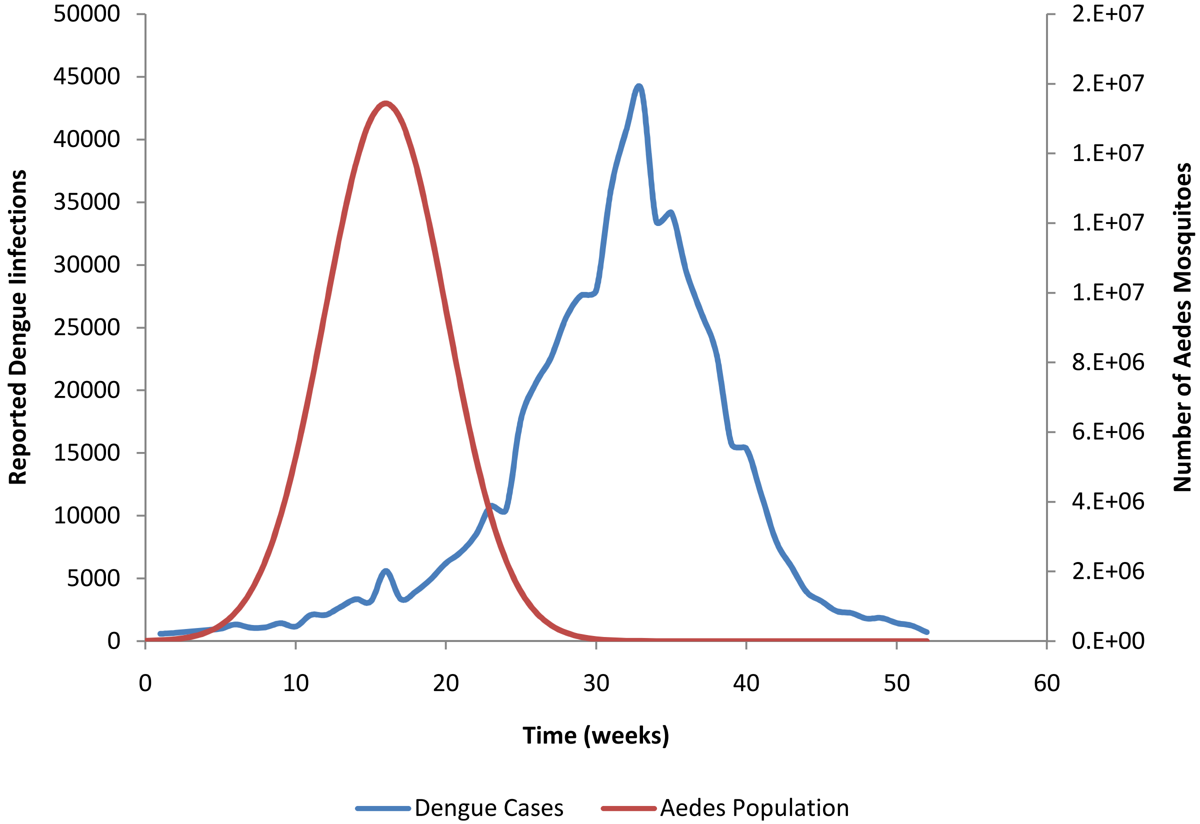
Jan-14
DENV 1
DENV 2
DENV 3
DENV 4
Unknown


Dengue Rio 2011-2012
Weekly Cases of Dengue Infections
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
10
20
30
40
50
60
Time (weeks)
Real
Fitted



50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Reported Dengue Iinfections
2.E+07
2.E+07
1.E+07
1.E+07
1.E+07
8.E+06
6.E+06
4.E+06
2.E+06
0.E+00
Number of Aedes Mosquitoes
0
10
20
30
40
50
60
Time (weeks)
Dengue Cases
Aedes Population

$$\frac{dS_H}{dt} = -abI_M \frac{S_H}{N_H} - \mu_H S_H + r_H N_H \left(1 - \frac{N_H}{\kappa_H}\right)$$

$$\frac{dI_H}{dt} = abI_M \frac{S_H}{N_H} - (\mu_H + \alpha_H + \gamma_H) I_H$$

$$\frac{dR_H}{dt} = \gamma_H I_H - \mu_H R_H$$

$$\frac{dS_M}{dt} = p_S c_S(t) S_E - \mu_M S_M - acS_M \frac{I_H}{N_H}$$

$$\frac{dL_M}{dt} = acS_M \frac{I_H}{N_H} - \gamma_M L_M - \mu_M L_M$$

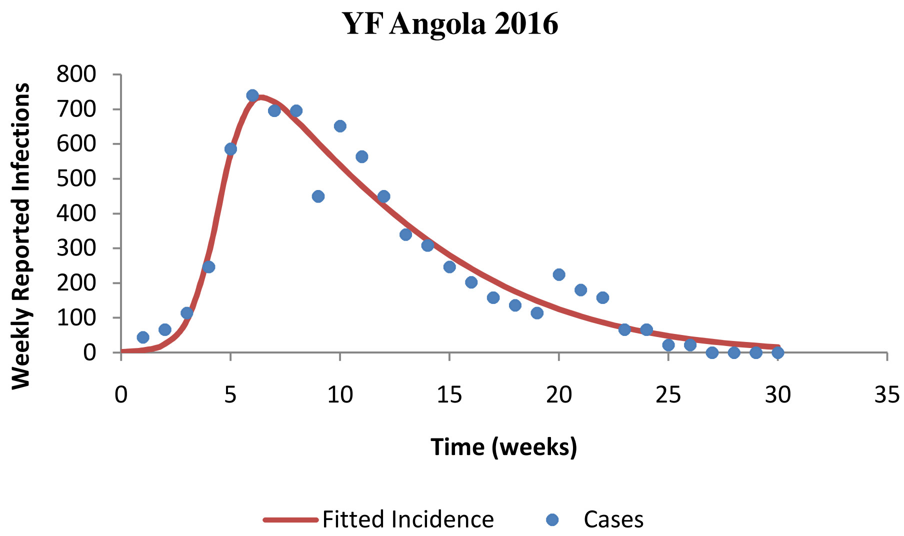
$$\frac{dI_M}{dt} = \gamma_M L_M - \mu_M I_M + p_I c_S(t) I_E$$

$$\frac{dS_E}{dt} = \left[r_M S_M + (1-g) r_M I_M\right]\left(1 - \frac{(S_E + I_E)}{\kappa_E}\right) - \mu_E S_E - p_S c_S(t) S_E$$

$$\frac{dI_E}{dt} = \left[g r_M I_M\right]\left(1 - \frac{(S_E + I_E)}{\kappa_E}\right) - \mu_E I_E - p_I c_S(t) I_E$$

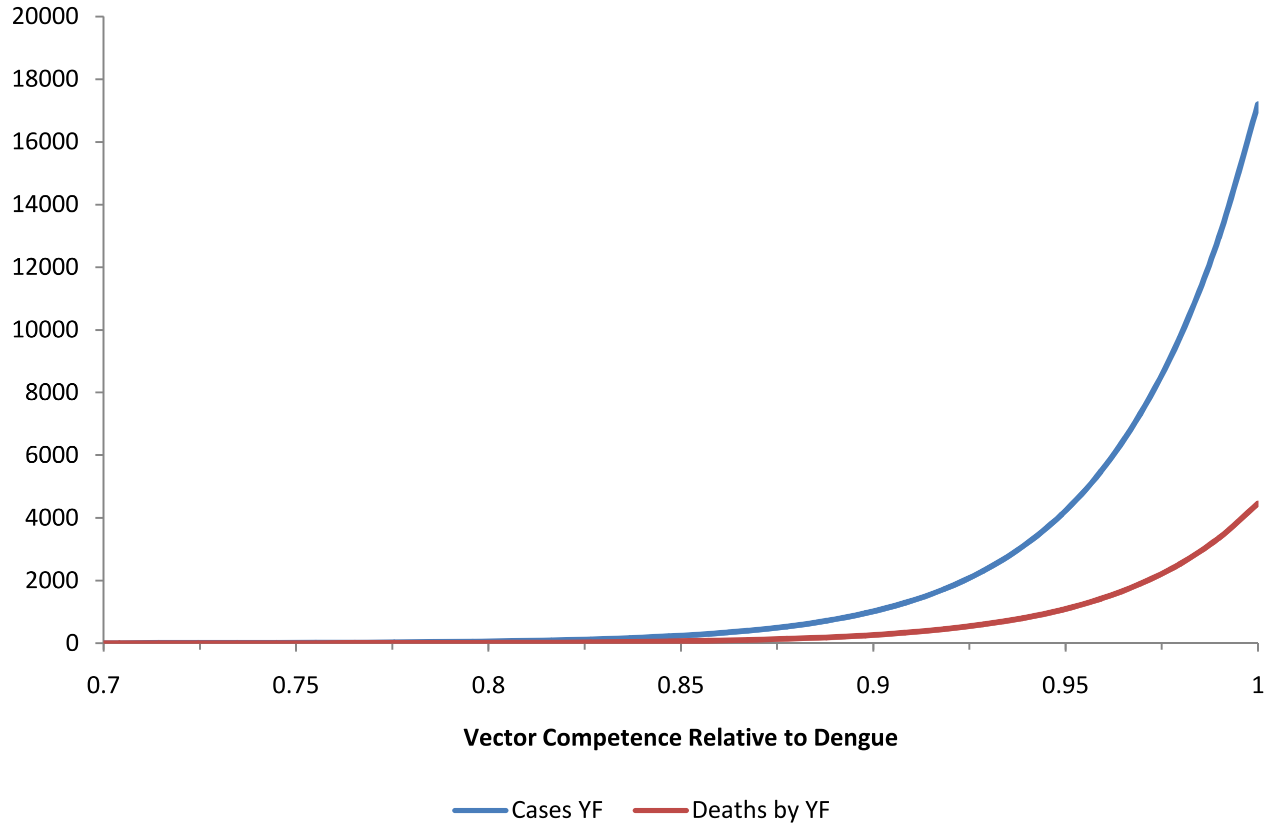
$$N_H = S_H + I_H + R_H$$

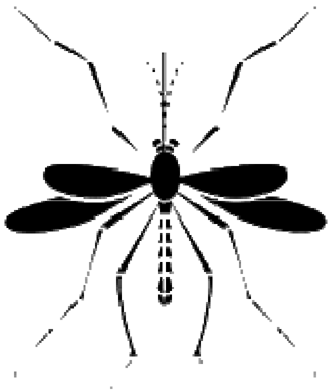
$$N_M = S_M + L_M + I_M$$



YF Angola 2016
Weekly Reported Infections
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
Time (weeks)
Fitted Incidence
Cases

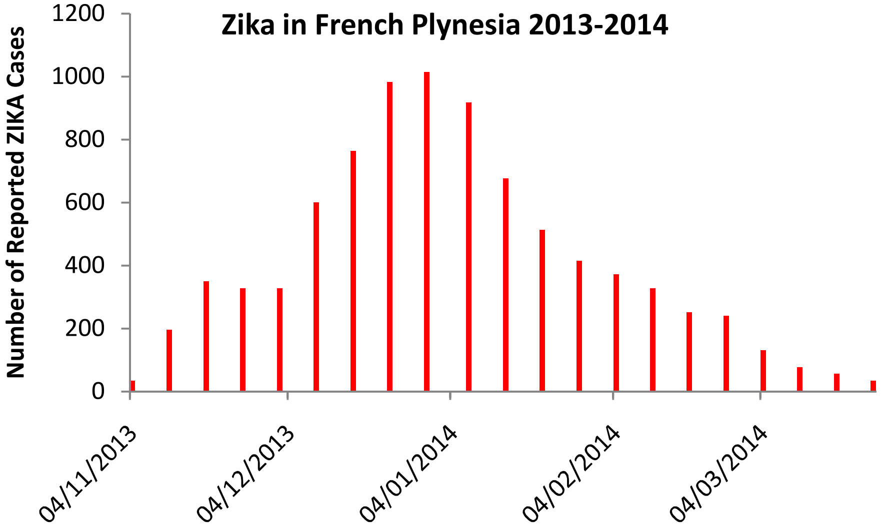
Relative Competence	Cases YF	Deaths by YF
0.663265	0.975483	0.304693
0.673469	1.3234	0.394874
0.683673	1.79483	0.517072
0.693878	2.43331	0.68257
0.704082	3.29757	0.906592
0.714286	4.46683	1.20967
0.72449	6.04786	1.61949
0.734694	8.18448	2.17331
0.744898	11.0703	2.92133
0.755102	14.9657	3.93105
0.765306	20.2209	5.29324
0.77551	27.3064	7.12985
0.785714	36.854	9.60465
0.795918	49.7116	12.9374
0.806122	67.016	17.4228
0.816327	90.2912	23.4559
0.826531	121.578	31.5657
0.836735	163.609	42.4603
0.846939	220.037	57.0868
0.857143	295.746	76.7111
0.867347	397.26	103.024
0.877551	533.284	138.282
0.887755	715.427	185.495
0.897959	959.157	248.671
0.908163	1285.06	333.147
0.918367	1720.5	446.017
0.928571	2301.83	596.701
0.938776	3077.21	797.685
0.94898	4110.4	1065.49
0.959184	5485.56	1421.94
0.969388	7313.48	1895.75
0.979592	9739.52	2524.6
0.989796	12953.5	3357.67
1	17201.6	4458.82


20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0.7
0.75
0.8
0.85
0.9
0.95
1
Vector Competence Relative to Dengue
Cases YF
Deaths by YF



ZIKA VIRUS

Zika virus has probably been introduced into Brazil by infected travellers from French Polynesia in 2013/2014



Zika in French Plynesia 2013-2014
Number of Reported ZIKA Cases
1200
1000
800
600
400
200
0
04/11/2013
04/12/2013
04/01/2014
04/02/2014
04/03/2014

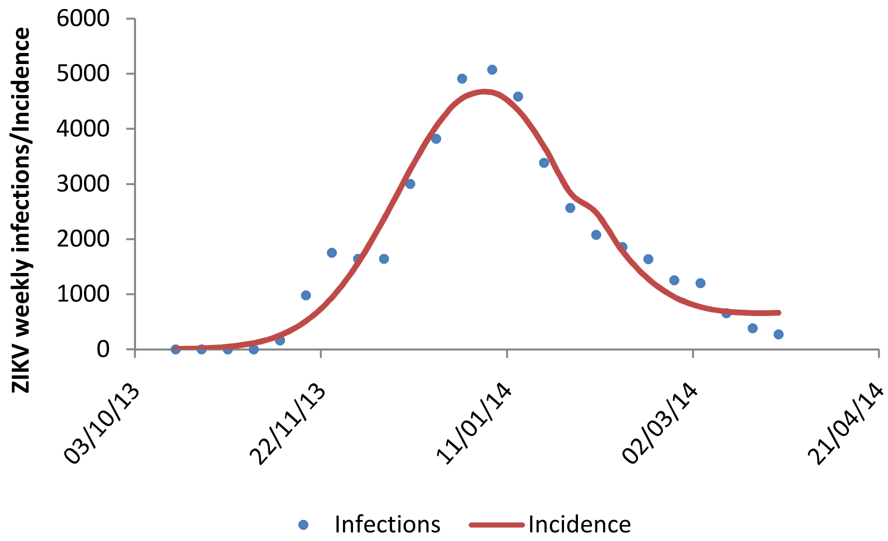
.

$$\lambda(t)S(t) = c_1 exp\left[-\frac{(t-c_2)^2}{c_3}\right]F(t)$$

$$F(t) = \frac{1}{1+\exp(-c_4(t-c_5))} + rect(t)c_6,$$

$$\frac{dS_H}{dt} = -\lambda(t)S_H(t) - \mu S(t)$$

$$\frac{dI_H}{dt} = \lambda(t)S_H(t) - (\mu+\alpha+\gamma)I_H(t)$$



ZIKV weekly infections/Incidence
6000
5000
4000
3000
2000
1000
0
03/10/13
22/11/13
11/01/14
02/03/14
21/04/14
Infections
Incidence

$$Risk(t) = 1 - \exp\left[-\int_{t_1}^{t_2} \lambda(t)\,dt \right]$$

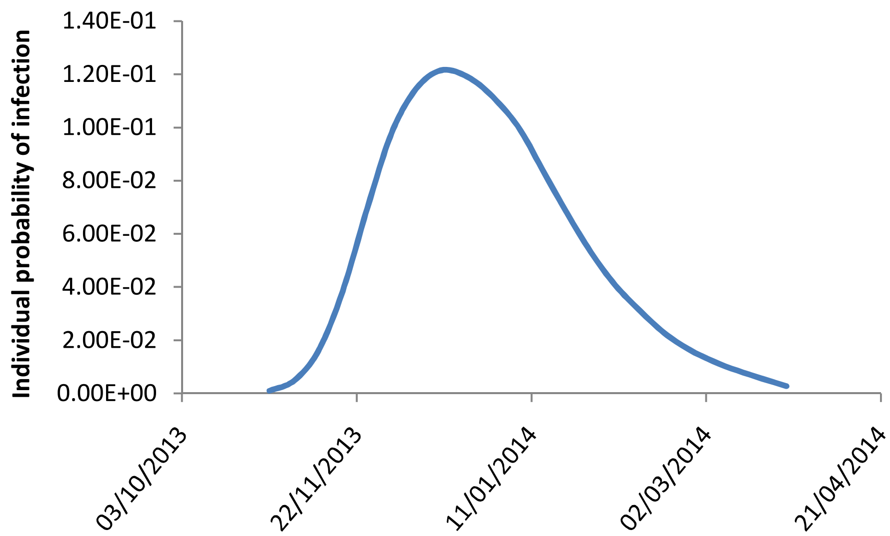
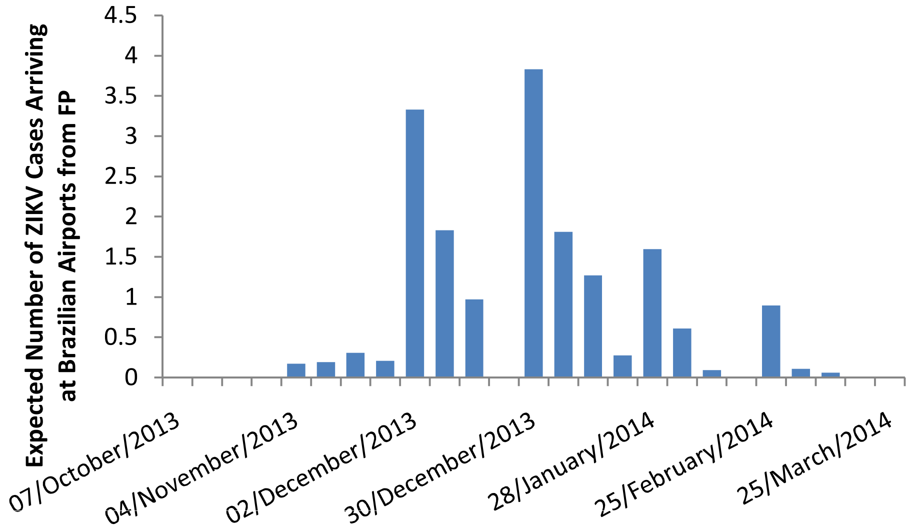


Table 1. Number of travellers departing French Polynesian airports with final destinations in Brazilian cities between December 2013 and February 2014			
Departure Month	**Departure Year**	**Destination City**	**Total Number**
December	2013	Sao Paulo	20
December	2013	Rio de Janeiro	14
December	2013	Recife	11
December	2013	Porto Alegre	5
December	2013	Florianopolis	4
December	2013	Curitiba	4
January	2014	Sao Paulo	18
January	2014	Sao Paulo	16
January	2014	Goiania	9
January	2014	Rio de Janeiro	9
January	2014	Curitiba	8
January	2014	Vitoria	7
January	2014	Fortaleza	2
January	2014	Rio de Janeiro	2
January	2014	Salvador	2
February	2014	Sao Paulo	20
February	2014	Porto Alegre	10
February	2014	Rio de Janeiro	9
February	2014	Curitiba	6
February	2014	Sao Paulo	4
February	2014	Uberlandia	2

Table 2. Individual risk of ZIKV infection in French Polynesia and the expected number of ZIKV infections exported to Brazil via travellers on commercial flights between December 2013 and February 2014

Week	Individual Probability of Infection	Expected Number of Travellers Infected with ZIKV
02/December/2013	0.0979584	3
09/December/2013	0.114501	2
16/December/2013	0.121446	1
23/December/2013	0.11955	0
30/December/2013	0.112717	4
07/January/2014	0.100661	2
14/January/2014	0.0845351	1
21/January/2014	0.068227	0
28/January/2014	0.0532315	2
04/February/2014	0.0407119	1
11/February/2014	0.0312288	0
18/February/2014	0.0227581	0
25/February/2014	0.0166078	1
Total		18



$$I_M(t) = \frac{N_M(0)I_H(0)}{N_H}\frac{ac}{(\mu_H + \gamma_H)}\left[1 - e^{-(\mu_H + \gamma_H)t}\right]e^{-\mu_M t}$$

Table 3. Estimated Basic Reproduction number $R_{0\text{-}ZIKV}$ for the selected Brazilian cities								
	Expected number of ZIKV infected travelers							
	Rio de Janeiro	São Paulo	Recife	Fortaleza	Salvador	Goiania	Vitoria	Total
Dec/2013	2	2	1	0	0	0	0	**5**
Jan/201414	1	3	0	0	0	1	1	**6**
Feb/2014	0	1	0	0	0	0	0	**1**
Total	3	6	1	0	0	1	1	**12**
$R_{0\text{-}ZIKV}$	**1.4**	**2.15**	**1.31**	**1.45**	**1.6**	**1.46**	**1.4**	

"Prediction is very difficult, especially about the future"
Niels Bohr

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