

1 Running head: Excel tool for Zika vector surveillance

2

3 **A location-specific spreadsheet for estimating**  
4 **Zika risk and timing for Zika vector surveillance,**  
5 **using U.S. military facilities as an example**

6 Desmond H. Foley<sup>1</sup>, David B. Pecor<sup>2</sup>

7 <sup>1</sup>Walter Reed Biosystematics Unit, Department of Entomology, National Museum of  
8 Natural History, Smithsonian Institution, Suitland, MD 20746, U.S.A.

9 <sup>2</sup>Walter Reed Biosystematics Unit, Division of Entomology, Walter Reed Army Institute  
10 of Research, 503 Robert Grant Avenue, Silver Spring, MD 20910, U.S.A.

11

12 **ABSTRACT**

13 Local Zika virus transmission in the United States involving one or both of the known  
14 vector species, *Aedes aegypti* and *Ae. albopictus*, is of major concern. To assist efforts  
15 to anticipate the risks of transmission, we developed an Excel spreadsheet tool that  
16 uses vector and virus temperature thresholds, remotely sensed maximum temperature,  
17 and habitat suitability from models to answer the questions: “is Zika transmission likely  
18 here?” and “when should we conduct vector surveillance?”. An example spreadsheet,  
19 updated regularly and freely available, uses near real-time and forecast temperature  
20 data to generate guidance, based on a novel four level Zika risk code, for 733 U.S.  
21 military facilities in the 50 states, the District of Columbia, and the territories of Guam  
22 and Puerto Rico.

23 **KEY WORDS:** Zika, *Aedes aegypti*, *Aedes albopictus*, Risk, Excel

## 24 INTRODUCTION

25 In 2016, Zika virus disease and congenital infections became nationally notifiable  
26 conditions in the United States (Council of State and Territorial Epidemiologists, 2016).  
27 A total of 2,382 confirmed and probable cases of ZIKAV disease with illness onset were  
28 reported to ArboNET, the U.S. national arboviral surveillance system managed by CDC  
29 and state health departments, during January 1 – July 31, 2016 (Walker et al. 2016). In  
30 July 2016 the first locally acquired cases of Zika virus (ZIKAV) from mosquitoes were  
31 confirmed for the U.S. state of Florida (Likos, 2016). *Aedes* mosquitoes transmit ZIKAV,  
32 chikungunya virus (CHIKV), dengue virus (DENV), and yellow fever virus (YFV), among  
33 others, so co-infections are possible. Although *Ae. albopictus* is thought to be a  
34 competent vector of ZIKAV (Grard et al. 2014), *Ae. aegypti* has been implicated as the  
35 primary transmitter of the virus in human populations in the ongoing outbreak in the  
36 Americas (Guerbois et al. 2016, Ferreira-de-Brito et al. 2016 ). This is likely the result of  
37 *Ae. aegypti* preferring to feed more frequently on humans (Scott et al. 1993, 2000), and  
38 being highly peridomestic compared to *Ae. albopictus*, which can inhabit more rural  
39 environments (Braks et al. 2003; Tsuda et al. 2006).

40 In this study, we concentrated on U.S. Department of Defense (DoD) facilities but  
41 the approach could be used for any area of interest. Some military facilities have long  
42 standing mosquito surveillance programs (Foley et al. 2011a), and Zika virus  
43 surveillance is being enhanced in the U.S. military as a result of the recent threat, for  
44 example, through funding from the Global Emerging Infections Surveillance and  
45 Response (GEIS), section of the Armed Forces Health Surveillance Branch in the  
46 Defense Health Agency's Public Health Division (Pellerin, 2016). According to a March  
47 2016 U.S. DoD memo, 190 DoD installations are located in areas where mosquitoes  
48 capable of carrying ZIKAV occur, and increased vector monitoring will be conducted in  
49 installations in 27 states, the District of Columbia, Guam and Puerto Rico (Kime, 2016).  
50 Four regional commands exist under the U.S. Army Medical Command, and all of these  
51 have Entomological Sciences Divisions that conduct mosquito surveillance. Additionally,  
52 the U.S. Air Force School of Aerospace Medicine, the U.S. Navy and Marine Corps  
53 Public Health Center and regional Navy Environmental and Preventative Medicine

54 Units, and the Navy Entomology Center of Excellence, assist those undertaking vector  
55 surveillance or arbovirus testing.

56 For a military entomologist tasked with establishing and maintaining an *Aedes*  
57 spp. / ZIKAV surveillance program in temperate areas that experience high mosquito  
58 seasonality, two important questions arise: 1) is ZIKAV transmission possible here?;  
59 and 2) when should we conduct vector surveillance?. In the following we describe an  
60 Excel-based tool that is designed to assist entomologists and other health personnel  
61 address these two questions.

62 Habitat suitability models displaying potential distribution have been published for  
63 both *Ae. aegypti* and *Ae. albopictus* (Attaway et al. 2016, Brady et al. 2014, Campbell et  
64 al. 2015, Khormi & Kumar 2014, Medley 2010), as well as for ZIKAV (Carlson et al.  
65 2016, Messina et al. 2016, Perkins et al. 2016, Samy et al. 2016). While these models  
66 often display average yearly suitability they do not necessarily provide information that  
67 could be used for decisions about the timing of surveillance activities, and are global in  
68 extent rather than focused on particular areas where a surveillance program might be  
69 established. Questions about timing of mosquito monitoring and allocation of resources  
70 requires a consideration of what conditions limit adult mosquito activity and ZIKAV  
71 dissemination in the field.

72 Relative humidity, rainfall, drought, and wind velocity affect survival and behavior  
73 of mosquitoes, and therefore transmission (Kramer & Ebel, 2003). However,  
74 temperature is the most important ecological determinant of development rate in *Ae.*  
75 *aegypti* (Courret & Benedict 2014), and one of the principal determinants of *Aedes*  
76 survival (Brady et al. 2013). Temperature also directly affects the replication rate of  
77 arboviruses, thus affecting the extrinsic incubation period (Gubler et al. 2007). What  
78 then, do we know about how temperature limits *Aedes* and arboviruses like ZIKAV?

79 In Saudi Arabia, Khormi et al. (2011) found that the minimum temperature range  
80 of 18-25 °C is suitable for *Ae. aegypti* survival, and the survival rate increases up to 38  
81 °C. Conner (1924) and Wayne & Graham (1968) found that *Ae. aegypti* is most active at  
82 temperatures between 15 °C and 30 °C, while other field and laboratory observations  
83 found survival rates from about 18 °C to ≤ 38 °C, based on daily or monthly minimum  
84 and maximum temperatures (Macfie, 1920; Bliss & Gill, 1933; Christopher, 1960). In a

85 study of *Ae. aegypti* distribution using the program CLIMEX, Khormi & Kumar (2014) set  
86 the limiting low temperature at 18 °C, the lower optimal temperature at 25 °C, the upper  
87 optimal temperature at 32 °C and the limiting high temperature at 38 °C. Brady et al.  
88 (2014) limited their predictions of temperature suitability to areas with a maximum  
89 monthly temperature exceeding 13°C for *Ae. albopictus* and 14°C for *Ae. aegypti*.  
90 These threshold temperatures were based on previous studies of the observed  
91 temperatures below which biting and movement behaviors are impaired [Christophers,  
92 1960; Estrada-Franco & Craig, 1995; Carrington et al. 2013a,b).

93 Studies suggest that an increase between 14-18 °C and 35-40 °C can lead to  
94 higher transmission of dengue (Wallis, 2005). Xiao et al. (2014) found that oral  
95 infections of DENV2 did not produce antigens in the salivary glands of *Ae. albopictus*  
96 kept at 18°C for up to 25 days but did produce antigens at 21°C during this period. It is  
97 not known if *Ae. albopictus* held longer at the lower temperature would have  
98 disseminated infections, but Dohm et al. (2002) found that *Culex pipiens* required 25  
99 days at 18°C to disseminate infections of West Nile Virus. For comparison, WNV is  
100 capable of replication from 14-45°C (Cornel et al. 1993, Kinney et al. 2006). Tilston et  
101 al. (2009) analyzed monthly average temperature of cities that experience chikungunya  
102 outbreaks and found that start and finish occurred when average monthly temperatures  
103 were 20°C or higher. At the upper temperature limit, Kostyuchenko et al. (2016) found  
104 that ZIKAV is more thermally stable than DENV, and is also structurally stable even  
105 when incubated at 40°C, mimicking the body temperature of extremely feverish patients  
106 after virus infection (but see Goo et al. 2016).

107 Remotely sensed temperature data is freely available from multiple sources as  
108 both near-real time recordings and forecast predictions. Combining remotely sensed  
109 temperature data with predicted distributions of the vectors and virus could provide  
110 insight into when areas of interest are suitable for transmission and should be actively  
111 monitored. Our aim was to produce a knowledge product and surveillance decision tool  
112 that makes use of publicly available information about potential distribution and thermal  
113 requirements of the vectors and virus at U.S. military facilities.

114

## 115 MATERIALS AND METHODS

### 116 **Areas of interest**

117 The location and boundary of U.S. military facilities was obtained from the US  
118 Census Bureau's TIGER/Line 2015 shapefile product  
119 (<http://www.census.gov/geo/maps-data/data/tiger.html>). This shapefile lists facilities in  
120 the continental United States (CONUS), Alaska, Hawaii, Puerto Rico and Guam. As  
121 some facility names comprised multi-part polygons, these were reduced from 804 to  
122 733, to match the number of unique facility names, using the Dissolve tool in ArcMap  
123 10.4 (ESRI, Redmond, CA – used throughout). The centroid of each facility was  
124 selected to produce a shapefile of points using the Feature to Point tool (inside polygon  
125 option checked) of ArcMap. The georeference of each point was obtained by the Add  
126 XY Coordinates tool and joined to the points shapefile. Extraction of all facility centroid  
127 raster values was first obtained by the Extract values to points tool then for polygons  
128 using the Zonal statistics as Table tool, and the results merged. This approach was  
129 needed because smaller polygons would not produce results using the Zonal statistics  
130 as Table tool, which necessitated using the raster data associated with the points for  
131 these facilities.

### 132 **Temperature data**

133 To monitor temperature in near real-time, daily time averaged maps of air  
134 temperature at the surface (Daytime/Ascending) were downloaded from the Giovanni  
135 4.19 (Released Date: 2016-04-12. Data provided by the NASA Goddard Earth Sciences  
136 (GES) Data and Information Services Center (DISC)) data portal at 1° spatial resolution.  
137 Daily gridded temperature analyses were also collected from the NOAA, U.S. National  
138 Weather Service Climate Prediction Center (CPC). Forecast temperature data was also  
139 provided by the CPC and the NOAA National Digital Forecast Database (NDFD) at 5 km  
140 spatial resolution. For predictions based on monthly averages, monthly gridded climate  
141 data with a spatial resolution of 1 km were downloaded from the WorldClim (Version  
142 1.4) Global Climate Data center.

### 143 **Habitat suitability models**

144 We chose the models of *Ae. aegypti* and *Ae. albopictus* by Kraemer et al. (2015),  
145 as these are recent and are based on an extensively documented set of presence  
146 observations for each vector. For this study, we used the habitat suitability model for  
147 ZIKAV transmission by Messina et al. (2016). The 0.5 model suitability score was  
148 arbitrarily used as the cut-off for presence/absence.

## 149 **Thresholds**

150 Temperatures suitable for activity of *Ae. aegypti* and *Ae. albopictus* combined  
151 was estimated as 13 – 38°C, and for ZIKAV this was 18 – 42°C. We acted  
152 conservatively by using temperatures at the extremes of the reported suitable  
153 temperature range, and maximum rather than mean air temperatures.

## 154 **Human population data**

155 In order to more fully understand the potential impact of ZIKAV risk to military  
156 and non-military personnel and their families in and around each facility, we explored  
157 risk in terms of human population data, with the following considerations. The flight  
158 range of *Ae. aegypti* and *Ae. albopictus* is in the order of hundreds of meters only  
159 (Honório et al. 2003, Harrington et al. 2005) and each facility would differ in the average  
160 distance that human carriers of ZIKAV would routinely travel to and from each facility.  
161 Additionally, some facilities are remote, while others are adjacent to or enclosed within  
162 urban and suburban areas. Despite these complications, we created a buffer of 5 km  
163 around all facility polygons to capture the human population density according to  
164 LandScan 2011 (Oak Ridge National Laboratory). This was accomplished using the  
165 LandScan raster and the Buffer and sum output in the Zonal Statistics as Table tools in  
166 ArcMap. A buffer of 5 km is a conservative estimate and is meant to give a uniform  
167 measure for each facility of the potential host density effected in an outbreak or vector  
168 control situation.

## 169 **Excel-based Zika risk tool**

170 A goal of this project was to display disparate data sources visually and in a  
171 simple and intuitive way in order to more effectively communicate the level of risk at

172 each military facility. The risk estimation and alert system needed to be in a format that  
173 was readily understandable and that can be easily accessed by military users, who  
174 often have IT security restrictions or bandwidth caps. We chose MS-Excel® (Microsoft  
175 Corp, Seattle, WA), as a universal platform for performing calculations and reporting  
176 results. This software had the added advantage that the scatterplot function can be  
177 used to map each military facility (Foley, 2011b), with icons displaying various  
178 categories of risk, and using a geocorrected map background (Esri, DeLorme, USGS,  
179 NPS. World Terrain Base - Sources: Esri, USGS, NOAA) for each U.S. State. Other  
180 notable features that were used in the Excel risk estimation tool were the formula  
181 functions, conditional formatting to represent categories of numbers as different types of  
182 symbols, dependent dropdown lists and hyperlinks to allow users to navigate more  
183 quickly to the results of individual facilities, and textualized results that users can read  
184 as statements describing the situation and as guidance for vector surveillance.

#### 185 **Calculations within the Excel Risk Estimation Tool**

186 Given the maximum temperature is available for a site (i.e. “Temp.”), the  
187 following lists an example sequence of tasks and their calculations, with explanations  
188 and the Excel formula (in square brackets), culminating in a risk rating:

- 189 1. Column A. “Was temperature suitable during period for the vector?”, i.e. if the  
190 maximum was 13 to 38°C, it is 1 otherwise 0 [ =IF((Temp.>=13)-  
191 (Temp.>38),1,0)],
- 192 2. Column B. “Was temperature suitable during period for virus replication in  
193 mosquito?”, i.e. if the maximum was 18 to 42°C, it is 1 otherwise 0 [  
194 =IF((Temp.>=18)-(Temp.>42),1,0)]
- 195 3. Column C. What is the sum of the thermal suitability values for vector (Column A)  
196 and virus (Column B)? (i.e. possible choices are: 0, 1 or 2)
- 197 4. Column D. If temperature for the vectors (Column A) was within the required  
198 range, what is the model suitability for vector?, i.e. this was the maximum  
199 modeled suitability (0 – 1.00) for either *Ae. aegypti* or *Ae. albopictus*



- 200 5. Column E. Score vector model suitability as 3 if  $\geq 0.5$ , otherwise 2 [=IF(Column  
201 D<0.5,2,IF(Column D $\geq$ 0.5,3))]. The 0.5 model suitability score was arbitrarily  
202 used as the cut-off for presence/absence.
- 203 6. Column F. If temperature for the virus (Column B) was within the required range,  
204 what is the model suitability for the virus? (0 – 1.00)
- 205 7. Column G. Score virus model suitability as 7 if  $\geq 0.5$ , otherwise 5 [=IF(Column  
206 F<0.5,5,IF(Column F $\geq$ 0.5,7))]. The 0.5 model suitability score was arbitrarily  
207 used as the cut-off for presence/absence.
- 208 8. Column H. What is the “Combined Score” for the interaction of temperature  
209 suitability of vector and virus, vector model suitability, and virus model suitability  
210 score (i.e. = C\*E\*G)? The use of 0, 1 and prime numbers for the component  
211 scores produces a unique semi-prime number for the product, i.e. 0, 10 (=1\*2\*5),  
212 14 (=1\*2\*7), 15 (=1\*3\*5), 21 (=1\*3\*7), 20 (=2\*2\*5), 28 (=2\*2\*7), 30 (=2\*3\*5), or  
213 42 (=2\*3\*7). A zero indicated that the temperature at the site was unsuitable for  
214 both vector and pathogen, so suitability scores were irrelevant, and combination  
215 scores were all scored zero.
- 216 9. The nine possible Combined Scores were divided into 6 categories based on  
217 whether preconditions do not exist for transmission, are unsuitable for  
218 transmission, are somewhat suitable for transmission, or are suitable for  
219 transmission (Figure 1).
- 220 10. Column I. An Overall Zika Risk Code was established based on the Combined  
221 Score (Figure 1), and rates conditions as low (Blue: Code 1) to high risk (Red:  
222 Code 4). The nine possible Combined Scores are initially divided according to  
223 whether temperature conditions are not suitable (Code 1), or suitable, for the  
224 vectors and virus (Codes 2 - 4). Codes 2 - 4 are then characterized according to  
225 increasing habitat suitability, with Code 4 being where models predict suitable  
226 habitat for vectors and virus.
- 227 11. Action statements were constructed based on the temperature and habitat model  
228 suitability scores (Figure 2). For example, if conditions are too cold for the  
229 development of the vectors, and models predict that the location is unsuitable for  
230 the vectors then the Action statement would be: “Too cold or hot for vectors -



231 surveillance unnecessary. When temp. suitable, model suggests vectors unlikely  
 232 or low numbers.". Alternatively, if conditions are warm enough for the  
 233 development of the vectors, and models predict that the location is highly suitable  
 234 for the vectors then the Action statement would be: "Temp. suitable for vectors -  
 235 surveillance may be needed. When temp. suitable, model suggests vectors likely  
 236 - may need control, education, and policies minimizing exposure."

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238 **Figure 1.** An overall Zika Risk Code based on the combined score, which rates  
 239 conditions from low risk (Blue: Code 1) to high risk (Red: Code 4).

Zika risk code	Detailed explanation	Preconditions for transmission	Combination score
<b>1</b>	Temperature not OK for Vector and Virus	Preconditions do not exist for Transmission	0
<b>1</b>	Temperature OK for Vector or Virus but not both. Model says habitat not very suitable for Vector	Preconditions do not exist for Transmission	10,14
<b>1</b>	Temperature OK for Vector or Virus but not both. Model says habitat suitable for Vector	Preconditions do not exist for Transmission	15,21
<b>2</b>	Temperature OK for Vector and Virus. Model says habitat not very suitable for Vector and Virus	Preconditions unsuitable for Transmission	20
<b>3</b>	Temperature OK for Vector and Virus. Model says habitat suitable for Vector or Virus but not both.	Preconditions somewhat suitable for Transmission	28,30
<b>4</b>	Temperature OK for Vector and Virus. Model says habitat suitable for Vector and Virus.	Preconditions suitable for Transmission	42

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248 **Figure 2.** Action statements constructed on the basis of the temperature and habitat  
 249 model suitability scores

Variable	Outcome	Action Statement
Temperature threshold for Zika vectors	Temperature below threshold (< 13° C )	Too cold for vectors - surveillance unnecessary.
	Temperature above threshold (=> 13° C )	Warm enough for vectors - surveillance may be needed.
Vector Suitability	Low vector suitability (< 50%)	When warm enough, model suggests vectors unlikely or low numbers.
	High vector suitability (=> 50%)	When warm enough, model suggests vectors likely - may need control, education, and policies minimizing exposure.
Temperature threshold for Zika virus	Temperature below threshold (< 18° C )	Too cold for Zika - surveillance unnecessary.
	Temperature above threshold (=> 18° C )	Warm enough for Zika - surveillance may be needed.
Zika Suitability	Low Zika suitability (< 50%)	When warm enough, model suggests Zika unlikely.
	High Zika suitability (=> 50%)	When warm enough, model suggests Zika likely - may need control, education, and policies minimizing exposure.
	No data	No Model result for vector suitability.

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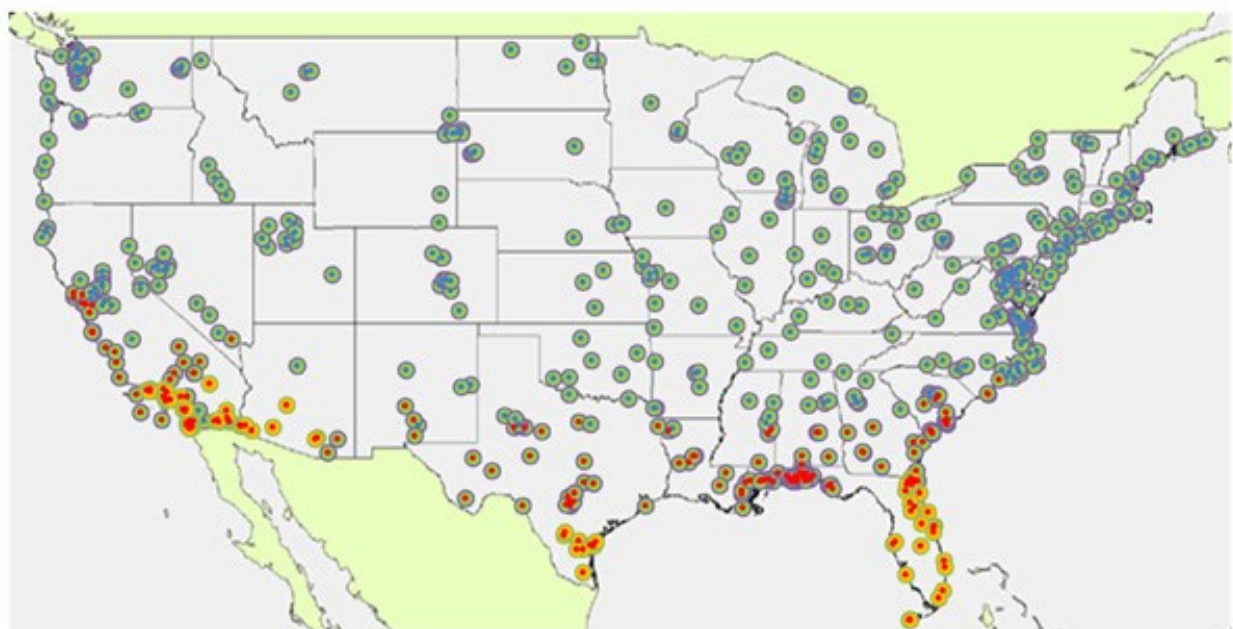
251

## 252 RESULTS

253 The Excel files provided comprise 12 monthly files based on average monthly  
 254 maximum temperatures (suitable for longer term planning), and near real-time and  
 255 forecast file, updated weekly. These files are freely available via the VectorMap website  
 256 ([http://vectormap.si.edu/Project\\_ESWG\\_ExcelZika.htm](http://vectormap.si.edu/Project_ESWG_ExcelZika.htm) ). The tool provides risk maps of  
 257 facilities as a continental overview (Figure 3), and on a U.S. State basis (Figure 4 ).  
 258 Results for individual facilities are navigable via dropdown menus and hyperlinks  
 259 (Figure 5). State-wide summary data of risk profile and humans potentially impacted is  
 260 given in Figure 6. The temporal changes in average risk based on the 12 monthly files is  
 261 given in Figure 7 in terms of the number of facilities affected (of 733) and the number of  
 262 people within 5 km of these facilities. April to October was the period of greatest risk  
 263 with suitable conditions for Zika transmission (i.e. code 4) potentially affecting a  
 264 maximum of 114 facilities in 12 states and territories, and 4,546,505 people within the  
 265 vicinity of these facilities, of a total of 32,811,618 within the vicinity of all 733 facilities.  
 266 The maximum number of facilities recording code 4 in any one month (e.g. August)  
 267 were: Florida (36), Hawaii (16), Louisiana (12), Texas (11), and Virginia (11). Of these,  
 268 the number of people within 5 km of these facilities were: Texas (1,215,230), Florida  
 269 (1,125,032), Louisiana (462,586), Virginia (409,066), and Hawaii (247,918).

270           These data may assist public health planning, and can be seen as an indicator of  
271 potential disease burden, or of people potentially benefiting from a well-informed vector  
272 surveillance and control program conducted within military facilities. Results are  
273 provided in a variety of symbologies and as textualized statements of how the factors  
274 examined may impact ZIKAV transmissions, and recommended actions for  
275 entomologists conducting routine vector surveillance. The action statement textualizes  
276 the data and is designed to assist a preparedness posture particularly around vector  
277 surveillance and control. Changes in the action statement over the year, for example as  
278 a result of rising temperature, can be used as a guide to affect changes in vector  
279 surveillance and control activities at particular facilities.

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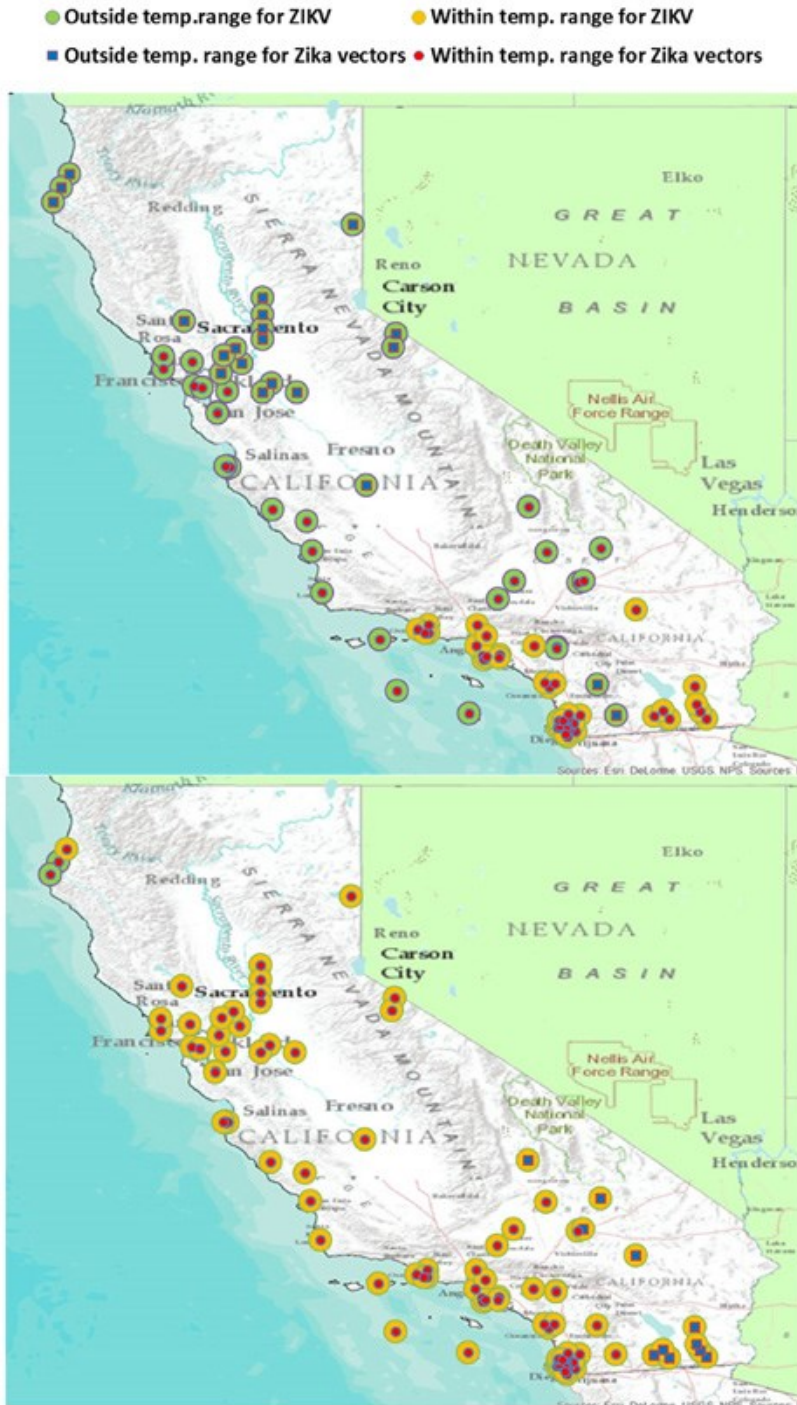


● Outside temp. range for ZIKV           ● Within temp. range for ZIKV  
● Outside temp. range for Zika vectors   ● Within temp. range for Zika vectors

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283 **Figure 3.** Average maximum temperature conditions for January for vectors and ZIKAV  
284 at military facilities within the lower 48 states of the U.S.

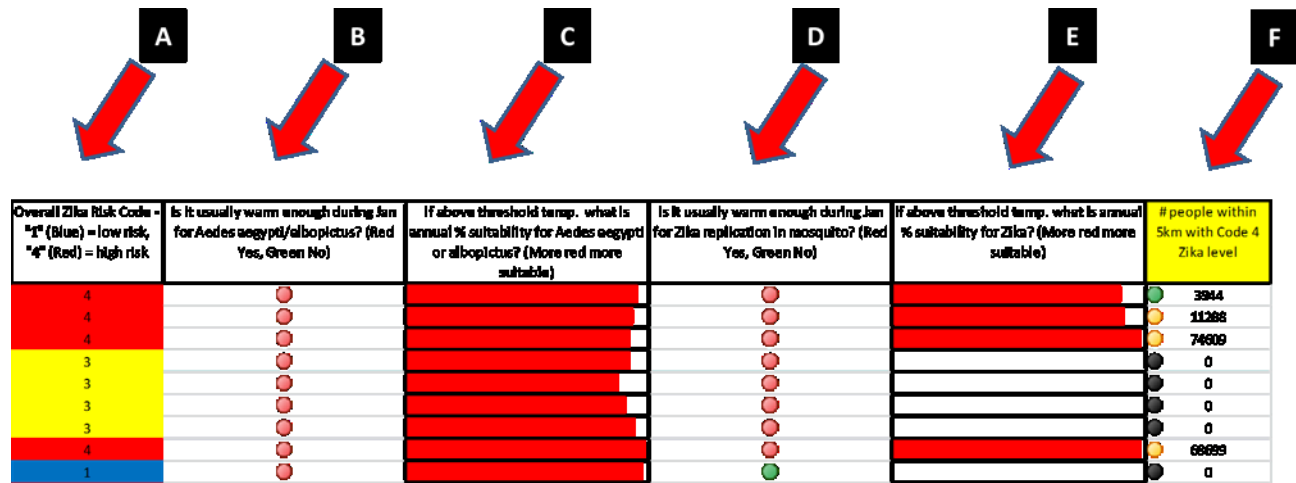


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286 **Figure 4.** Thermal conditions for January (above) and August (below) for vectors and  
287 ZIKAV at military facilities in California. Note, unsuitable conditions in August in the  
288 south are due to temperatures being too high for the vectors.

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293 **Figure 5.** An overall Zika virus risk code for near real-time and forecast periods (A) is  
 294 assigned based on a combination of: temperature suitability for adult activity of the  
 295 vectors (*Ae. aegypti* and *Ae. albopictus*) (B), modeled habitat suitability of the vectors  
 296 (C), temperature suitability for Zika virus replication within the vectors (D), and modeled  
 297 habitat suitability of Zika virus transmission (E). If suitable conditions exist (Zika Risk  
 298 Code 4), the number of people within 5 km is shown (F) as one indication of the number  
 299 of potential hosts in the vicinity, or the number of humans potentially benefiting from  
 300 facility-wide vector surveillance and control programs.

301



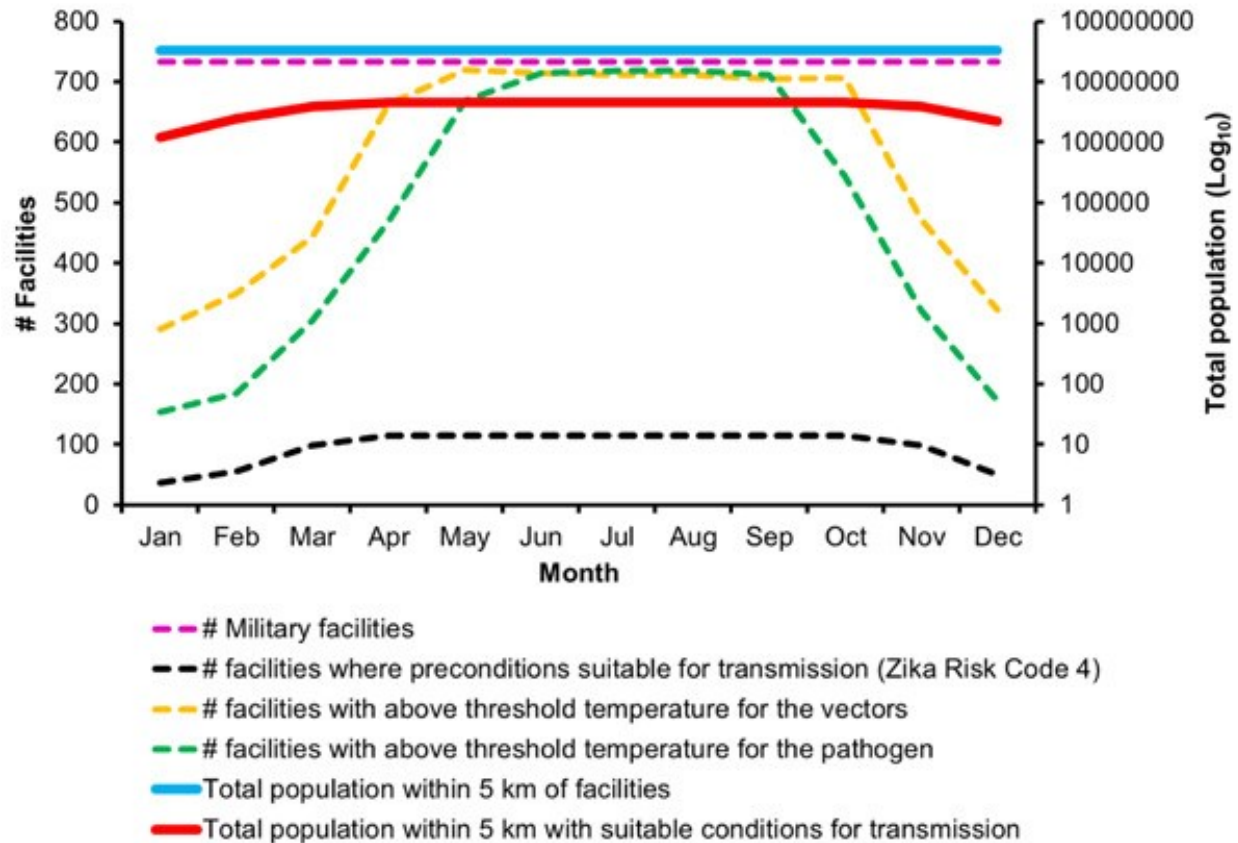
## Summary of Vector hazard during January for U.S. Military facilities by State for Zika virus

State	# Military facilities <sup>1</sup>	Zika Risk Code <sup>2-5</sup> (average)	# facilities where preconditions suitable for transmission (Zika Risk Code 4) <sup>5</sup>	# facilities with above threshold temperature for the vectors <sup>6</sup>	# facilities with above threshold temperature for the pathogen <sup>7</sup>	Total population within 5 km of facilities <sup>8</sup>	Total population within 5 km with suitable conditions for transmission
Alaska	20	1	0	0	0	357,044	0
Alabama	14	1	0	10	0	553,648	0
Arkansas	4	1	0	0	0	187,622	0
Arizona	11	2.19	0	10	0	556,120	0
California	100	1.71	0	79	0	6,655,724	0
Colorado	9	1	0	0	0	386,446	0
Connecticut	10	1	0	0	0	212,038	0
District of Columbia	8	1	0	0	0	842,772	0
Delaware	2	1	0	0	0	52,946	0
Florida	48	2.44	17	48	1	1,373,859	653,556
Georgia	16	1	0	9	0	1,021,113	0
Hawaii	36	3.2	16	36	1	980,370	247,918
Iowa	2	1	0	0	0	266,567	0

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303 **Figure 6.** Summary risk data for each U.S. State to assist with public health and  
 304 resource allocation planning.

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307 **Figure 7.** Summary risk data for 733 U.S. military facilities over 12 months.

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## 309 DISCUSSION

310 This Excel tool is designed to provide insights into ZIKAV transmission potential  
311 at U.S. military facilities, but could be applied to other arboviruses and situations, such  
312 as cities (Monaghan et al. 2016), tire dumps or parks. The spreadsheet is flexible in that  
313 vector and virus suitability model scores, temperature limits, and the wording of action  
314 statements can be replaced depending on the context, and as new information comes  
315 to light.

316 For U.S. military situations, this tool could be used in conjunction with the  
317 Electronic Surveillance System for the Early Notification of Community-based  
318 Epidemics (ESSENCE) or Medical Situational Awareness in Theater (MSAT), which



319 reports on febrile illnesses and rash in the military population. Coordination of result  
320 reporting through the Armed Forces Pest Management Board (AFPMB) and VectorMap  
321 may also be desirable. The Navy and Marine Corps Public Health Center's guide  
322 (NMCPHC, 2016) states that "each installation's medical personnel should conduct  
323 ongoing *Aedes* surveillance during the mosquito season appropriate to their region and  
324 take preventive and responsive action to reduce disease risk to active duty, government  
325 employees, and family member populations". In addition, the DoD instruction  
326 OPNAVINST 6250.4C "requires all Navy and Marine Corps installations to have an  
327 Emergency Vector Control Plan (EVCP) for disease vector surveillance and control  
328 during disease outbreaks". The spreadsheet described in this study should complement  
329 "installation pest management plans, including the EVCP, as a way to assess the risk of  
330 vector borne diseases, and implement strategies to reduce the risk to personnel  
331 assigned to installations" (NMCPHC, 2016).

332         Knowing when conditions are suitable for vectors is crucial for monitoring the  
333 success or failure of any control program. Appendix C of NMCPHC (2016) consists of a  
334 chart to determine the risk of infection on an installation and when to apply vector  
335 control measures. This four level vector threat response plan relies on information about  
336 vector abundance and reports of disease transmission. We see the Excel spreadsheet  
337 risk tool as a valuable adjunct to the NMCPHC plan, as it would assist with defining the  
338 length of the mosquito season, and the judicious deployment and timing of  
339 entomological resources. Each military facility is unique, and varies in size, function,  
340 human density, and suitable mosquito habitat, so not all of the 733 facilities addressed  
341 in this study will be at risk of mosquito-borne disease and suitable candidates for  
342 mosquito surveillance. However, all locations, at worst, should be useful as a point of  
343 reference for other nearby locations where mosquito surveillance is conducted.

344         The Zika Risk Code developed here (Figure 1) derived some inspiration from  
345 Figure 3 of Fischer et al. (2013), who combined models of vector habitat suitability with  
346 temperature categories for CHIKV replication to produce a matrix of climate related risk  
347 classes.

348 It is important to note that each data source used in this analysis has the  
349 potential for errors which should be considered when determining risk. For example,  
350 habitat suitability models for each vector may not be accurate for all areas, and only  
351 predict average yearly suitability. Temperature data refers to the maximum day-time air  
352 temperature near the surface (averaged over various spatial resolutions) from daily data  
353 for a recent date range, which NASA acknowledges has limitations. Vectors can also  
354 seek microclimates (e.g. indoors, subterranean habitats) that may be warmer or cooler  
355 than the outside temperature that is estimated by remote sensing data. Temperatures  
356 within the suitable range may not effect organisms uniformly. According to Westbrook et  
357 al. (2010) adult females reared from immature stages at 18°C, were six times more  
358 likely to be infected with CHIKV than females reared at 32°C. Westbrook et al. (2010)  
359 noted that climate factors, such as temperature, experienced at the larval stage, which  
360 would not be detected by adult trapping programs, can influence the competence of  
361 adult females to vector arboviruses.

362 We also do not account for temperature fluctuations; according to Lambrechts et  
363 al. (2011), mosquitoes lived longer and were more likely to become infected with DENV  
364 under moderate temperature fluctuations, than under large temperature fluctuations.  
365 Thangamani et al. (2016) and Ferreira-de-Brito et al. (2016) found that ZIKAV can be  
366 vertically transmitted in *Ae. aegypti* but not *Ae. albopictus*. This capability suggests  
367 mechanisms for the virus to survive in eggs that can survive for months in a dried  
368 dormant state during adverse conditions, e.g. a harsh winter that would normally kill  
369 adults.

370 The risk levels calculated in the spreadsheets deliberately uses simplified  
371 assumptions about temperature and does not consider precipitation, interspecific  
372 competition, anthropogenic factors such as imported cases, built-up areas, vegetation  
373 indices, and economic indices that can modify risk in complex and less understood  
374 ways. It is recommended that a level of caution be taken when interpreting the data  
375 provided by this system. It is wise to monitor activity in surrounding facilities and any  
376 reputable information from other sources before acting on any recommendations given  
377 here. It is further recommended that the near-real time and forecast analysis should be

378 viewed in conjunction with the monthly average Excel vector hazard files which uses  
379 average monthly maximum temperature, to gain further longer term insights into where  
380 thermal conditions will support vector activity.

381

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