Temporal Trends and Regional Variability of 2001-2002 DENV-3 Epidemic in Havana City: Did Hurricane Michelle Contribute to its Severity ?

Ying-Hen Hsieh, Hector de Arazoza, Rachid Lounes

Temporal Trends and Regional Variability of 2001-2002 DENV-3 Epidemic in Havana City: Did Hurricane Michelle Contribute to its Severity?

Ying-Hen Hsieh[1], Hector de Arazoza[2,3], Rachid Lounes[3]

[1]Department of Public Health and Center for Infectious Disease Education and Research, China Medical University, Taichung, Taiwan 40402

[2]Department of Mathematics, University of Havana, San Lazaro y L, Ciudad de La Habana, Cuba,

[3]Laboratoire MAP5, UMR-CNRS 8145, Université Paris Descartes, 75270 Paris Cedex 06, FRANCE

Running Title: 2001-2002 dengue outbreak in Havana

Word count: 2239

Correspondence to: Department of Public Health and Center for Infectious Disease Education and Research, China Medical University Taichung, 91 Hsueh-Shih Road, Taichung, Taiwan 404. Tel and fax: 886-4-22075913, email:hsieh@mail.cmu.edu.tw

Abstract

Background

In 2001, dengue transmission was detected in Havana City where 12,889 cases, mostly of DENV-3 type, were reported with 78 DHF cases and 3 deaths due to Dengue

Methodology/Principal Findings

A simple mathematical model, the Richards model, is utilized to investigate the temporal progression of the epidemic in 14 municipalities in Havana City and to quantify the transmissibility of the epidemic via the basic reproduction number R_0. Model fits using weekly reported dengue case data for each of the municipalities as well as for all of Havana City indicate either a 2-wave or 3-wave outbreak. Estimates for R_0 vary from 1.97, 95% CI: (1.94, 2.01), for Arroyo Naranjo to 61.06 (60.44, 61.68) for Boyeros.

Conclusions/Significance

Wide regional variability in our estimates of R_0 for dengue is consistent with reported values in literature from various regions of the world, most likely due to heterogeneity in community structure, community-wide pre-immunity, geographical locations, and social networking. By case reporting week, the dengue epidemic in Havana had started to go down initially around weeks 20-22 (first turning point/peak incidence). However, infections spread once again after week 24, perhaps due to Hurricane Michelle, one of the most destructive and wettest tropical cyclones ever in Cuba that may have contributed to a protracted and more severe epidemic. For all municipalities with 3-wave, model fit indicates a new third wave occurred after Christmas/New Year in weeks 31-32, likely attributable to a decrease in reporting due to reluctance for hospital visits during the holidays. Our result illustrates the potential impact of climatological events on disease spread. It further highlights the need to be well-prepared for possible worsening disease spread in the aftermath of natural disasters such as hurricanes/typhoons.

Keywords: Dengue; Cuba; DENV-3; mathematical model; basic reproduction number; turning point; Hurricane Michelle.

Author Summary

The 2001-2002 DENV-3 epidemic in Havana City lasted almost 7 months with more than 10,000 cases, 78 DHF cases, and 3 deaths. One of the turning point of the multi-wave epidemic coincided with the occurrence of Hurricane Michelle, one of the most destructive and wettest tropical cyclones ever in Cuba that may have contributed to a protracted and more severe epidemic. Estimate of the basic reproduction number R_0 for each municipality reveals wide regional variability exhibited which is consistent with reported values of R_0 for dengue in literature in various regions of the world. Interestingly, for some municipalities with 3 waves, the start of the third wave coincided with the end of the Christmas/New Year holiday, possibly attributable to decrease reporting during the holidays. Our result illustrates the potential impact of climatological events on disease spread. It further highlights the need for health community to be aware and better prepared for the possibility of a worsening disease spread in the aftermath of natural disasters such as hurricanes/typhoons.

Introduction

Dengue virus infection in humans causes a spectrum of illness ranging from asymptomatic or mild febrile illness to severe and fatal hemorrhagic disease. Infection with any of the four known serotypes of Dengue (DENV-1, DENV-2, DENV-3, and DENV-4) causes a similar clinical presentation that may vary in severity, depending on the strain and serotype of the infecting virus and the immune status, age, and genetic background of the human host. Due to its wide spread and multiple serotypes, the disease, even in absence of fatal forms, produces significant economic and social costs in terms of absenteeism, immobilization, debilitation, medication, and death).

In Cuba, Dengue viruses are transmitted by the Aedes aegypti mosquito. The mosquito is characterized by its biting pattern, which consists of multiple blood meals during each egg-laying cycle, and its ability to grow in water reservoir during of its immature stages (i.e., egg, larva and pupa). These features make it an ideal vector for dengue virus transmission, especially in large urban areas where the human population density is high with abundant artificial containers in where the aquatic stages of Aedes aegypti flourish [1]. Aedes aegypti is infected by sucking infected human blood, while humans are infected with dengue viruses when bitten by an infective mosquito. The global spread of dengue can be directly attributable to the proliferation and adaptation of mosquitoes.

Currently the only way to control and reduce dengue transmission is to implement alternative strategies such as: (i) reduction of vector populations in both the adult (by fumigation and/or by other chemical/biological treatments [2]) and the immature stages (by eliminating breeding sites); (ii) early detection of infected humans to prevent the virus transmission to susceptible mosquitoes. In Cuba the rainy season (lasting 6 months from May to October) produces a proliferation of mosquito populations which includes Aedes aegypti. This persistent presence of Aedes aegypti, together with the increased international arrivals from dengue-endemic countries in recent years, has led to several outbreaks including a major 2001 outbreak in Havana City [3].

In the Caribbean region the first major outbreaks of dengue fever (with a significant number of severe cases) occurred in Cuba in 1977 (with DENV-1) and in 1981 (with DENV-2). Both epidemics affected the entire country, producing more than 500,000 and 300,000 dengue cases, respectively. In 2000, a minor outbreak of dengue was detected in Havana City with 138 cases of DF, when DENV-3 and DENV-4 viruses were isolated. In 2001, dengue transmission was detected in Havana City where 12,889 cases, mostly of DENV-3 type, were reported with 78 DHF cases and 3 deaths due to Dengue [3].

To ascertain how did this epidemic come to pass, we will employ a simple mathematical model, the Richards model, to investigate the temporal progression of the epidemic in various municipalities in Havana City and to quantify the transmissibility of the epidemic via the basic reproduction number R_0.

Methods and Materials

Data

The 2001-2002 dengue outbreak data, by reporting week, for each of the 15 municipalities in Havana City are obtained from the Pedro Koury Tropical Medicine Institute (IPK) in Havana, Cuba, which spans from May 30, 2001 to February 27, 2002. We designate the first calendar week (Sunday to Saturday) with reported case in Playa, from May 27 to June 2, 2001, as week 1 of our data. Subsequently the data spans 40 weeks, with week 40 covering February 24-March 2, 2002.

The Richards model

We fit the data to the Richards model [4]: where $C(t)$ is the cumulative number of cases reported at time t (in weeks). Here the prime “” denotes the rate of change with respect to time. The model parameter K is the maximum case number (or final outbreak size) over a single phase of outbreak, r is the per capita growth rate of the infected population, and a is the exponent of deviation. The solution of the Richards model is , where t_i is the turning point of the epidemic (or the inflection point of the cumulative case curve) and *ln* denotes the natural logarithm. Using the Richard model, we can directly fit empirical data from a cumulative epidemic curve to obtain estimates of epidemiological meaningful parameters, including the growth rate r.

In such a model formulation, the basic reproduction number R_0 is given by the formula , where T is the disease generation time defined as the average time interval from infection of an individual to infection of his or her contacts. It has been shown mathematically that, given the growth rate r, the equation provides the upper bound of the basic reproduction number regardless of the distribution of the generation interval used [5]. Additional technical details regarding the Richards model can be found in [6-8].

The turning point or inflection point t_i of the cumulative case data, defined as the time when the rate of case accumulation changes from increasing to decreasing (or vice versa) can be easily pinpointed as the point where the rate of change transitions from positive to negative; i.e., the moment at which the trajectory begins to decline. For epidemics with two or more phases, a variation of the S-shaped Richards model has been proposed [7]. This multi-staged Richards model distinguishes between two types of turning points: the initial S-Shaped cumulative case curve which signifies the first turning point that ends initial exponential growth, or simply the time where peak incidence of a wave of cases occurs; and a second type of turning point in the cumulative epidemic curve where the growth rate of the number of cumulative cases begins to increase again, signifying the beginning of the next wave. This variant of Richards model provides a systematic method of determining whether an outbreak is single- or multi-phase in nature, and can be used to distinguish true turning points from peaks and valleys resulting from random variability in case counts. Readers are also referred to [9, 10] for its applications to dengue, and to [11-14] for applications to 2009 H1N1. Model parameter estimates based on the explicit solution of the Richards model can be obtained easily and efficiently using any standard software with a least-squares approximation tool, such as SAS or Matlab.

Results

The results of the best Richards model fit for 14 of 15 municipalities in Havana City, with estimates for t_i, r, K, R_0 and their respective 95% confidence intervals (CI), are listed in Table 1. The municipality of Cotorro had only 34 reported cases scattered over 20 weeks and therefore cannot be fitted. We also fitted the combined total case data of all 15 municipalities in Havana City including Cotorro (see Table 1b), for the purpose of comparison. Note that the week in which the true turning point for each wave occurred is t_i weeks (3^{rd} column in the tables) after the first week of the wave, rounding off to the next integer week. For example, the turning points for the three waves in Playa occurred in weeks 18 (3+14.3 in the first row of Table 1a), 25 (22+2.46), and 35 (30+4.38), respectively.

The model fits for the most severely affected municipalities, namely Playa (with the first reported case of this epidemic), Plaza, Central Havana, and Old Havana, as well as for all 15 municipalities of Havana City, are given in Figure 1.

All model fits indicate a 2-wave or 3-wave outbreak for each of the 14 municipalities as well as for all of Havana City. Outbreaks in Old Havana, Regla, and Guanabacoa only are 2-wave, while all other municipalities exhibit 3-wave outbreaks. For the purpose of comparing regional heterogeneity, we also provide timeline graphs of the 14 fitted municipalities in Figure 2.

Conclusions and Discussion

Previous large dengue epidemics in Cuba were associated with DENV-1 (in 1977) and DENV-2 (in 1981). More recently, two smaller dengue outbreaks were reported in 1997 (DENV-2) and September 2000 (DENV-3 and DENV-4) [3]. Subsequently, there was very little pre-existing immunity among the population in Havana for this 2001-2002 DENV-3 epidemic, although some cases of DHF/DSS might have occurred in persons infected with DENV-3 in a background of immunity to DENV-1 and DENV-2 from either the 1981 epidemic or dengue epidemics during or before the 1940s [15]. Table 1 indicate that the estimates for R_0 in the initial wave vary from 1.974 (95% CI: 1.941, 2.006) for Arroyo Naranjo to 61.062 (60.444, 61.680) for Boyeros, with high disease transmissibility (large R_0) in the initial wave, followed by succeeding waves with smaller R_0. The wide regional variability exhibited in our estimates is consistent with other reported values of R_0 for dengue in literature in various regions of the world (see, e.g., [16] or Table 2 in [10]), most likely due to heterogeneity in community structure, community-wide pre-immunity, geographical locations, and social networking.

Moreover, there is also a clear regional heterogeneity in the temporal trend, where Old Havana, Regla, and Guanabacoa are 2-waved while the other municipalities are 3-waved. Even Central and Old Havana, which are closely nearby, are fitted different with Central Havana have an additional wave occurring on week 31. However, there are also sample similarities.

Except for Playa, Regla, and Guanabacoa (the latter 2 regions with late outbreaks having the first cases reported in September), all other municipalities as well as all of Havana City had a first turning point (peak incidence) during weeks 20-22 indicating a downturn of cases, regardless whether the data fit exhibits a 2-wave or 3-wave outbreak. Moreover, with the exception of Arroyo Naranjo, Regla, and Guanabacoa, all other municipalities as well as all of Havana City has a turning point of second type around weeks 22-24 that signals an increase in case number and the beginning of a new wave of cases, regardless whether it has a 2-wave or 3-wave outbreak. Interestingly, all 14 municipalities had a turning point (peak incidence) during weeks 25-30, regardless of the number of waves or the timing of initial outbreak. Finally, for all 11 municipalities with 3 waves, the third wave started around weeks 30-32. The last turning point (peak incidence), or a downturn toward the end of the outbreak, came during weeks 33-36 for all municipalities except Old Havana which had a 2-wave outbreak.

More significantly is the underlying cause of this multi-wave epidemic. For the first wave, we note that Hurricane Michelle, the most destructive hurricane in the history of Cuba based on its actual damage [17], struck Cuba on November 4, 2001, the first day of week 24 in our study. Landing on the coast of western and southern Cuba, Michelle was one of the wettest tropical cyclones ever in Cuba [18], produced 4–5 foot waves along with a heavy storm surge. Rainfall amounting up to 754 mm was recorded across the island [19]. Previous studies (e.g., [10], [20], [21]) have proposed that extreme weather conditions, such as typhoon or hurricane which brings substantial amount of precipitation, can be shown to be significantly correlated to the occurrence of a wave of reported dengue cases with a lag of several weeks. The typhoon/hurricane first brings a sudden drop in temperature causing mosquito inactivity and decreased biting/infection, the ensuing heavy rainfall then leads to increased breading reservoir for the larvae to proliferate. It is hence conceivable that Hurricane Michelle had contributed to, if not actually causing, the new wave of cases in these municipalities after week 24. In other words, the dengue epidemic in Havana had started to go down initially around weeks 20-22 (first turning point/peak incidence), but spread once again after week 24 after Hurricane Michelle, causing a more severe and longer-lasting epidemic. We note that, since the case data is by reporting week, there is a delay of around one week from actual infections to reporting, mainly due to intrinsic dengue incubation period of 4-7 days.

After a downturn (peak incidence) around weeks 25-30, a new turning point (of second type) for start of a third wave after weeks 30-32 for all 11 municipalities with 3-wave fit (excluding Old Havana, Regla, and Guanabacoa) is also interesting since Christmas and New Year happened to fall on, respectively, weeks 31 and 32. However, the new wave of reported cases is likely attributable to a decrease in reporting due to reluctance on the part of some ill persons for hospital visits during the holidays. Our result illustrates the potential impact of climatological events on disease spread. It further highlights the need for health community to be aware and better prepared for the possibility of a worsening disease spread in the aftermath of natural disasters such as hurricanes/typhoons.

During the 1981 dengue epidemic, the Cuban health authorities started a National Program for Eradication of Aedes aegypti which has continued to the present. The campaign was based on the principles of dengue control established by the Pan American Health Organization (PAHO) Guidelines [22] with the involvement of the whole community (governmental and political bodies at all levels, householders, community organizations, etc.), where thousands of workers were mobilized with the task of periodic inspection of housing, detection and elimination of breeding points for the vector, chemical control of mosquitoes, and an educational campaign. These activities were carried out regularly and reinforced whenever cases of dengue are detected. The 2001 epidemic was no exception ([3]), which may have contributed to the 2001 epidemic being less severe than the previous epidemics in 1977 and 1981. Community-wide cross pre-immunity from earlier epidemics may also have played a role, which is however difficult to gauge without sizable serologic dataset.

Financial Disclosure

Funding provided by National Science Council of Taiwan under grants (NSC 100-2314-B-039 -028-MY3, 100-2115-M-039-002). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Conflict of Interest

We declare that we have no competing interest.

Acknowledgments

We would like to thank the Tropical Medicine Institute Pedro Kouri for access to the data used for this study.

Author Contributions

Conceived and designed the experiments: YHH HaD RL. Data acquisition and management: HaD RL. Analyzed the data: YHH. Wrote the paper: YHH HaD.

References

1. Hammond SN, Gordon AL, Lugo E, Moreno G, Kuan GM, et al (2007) Characterization of Aedes Aegypti (Diptera: Culicidae) Production Sites in Urban Nicaragua. J Med Entomol. 44(5): 851-860.

2. Thomé RCA, Yang HM, Esteva L (2010) Optimal control of Aedes aegypti mosquitoes by the sterile insect technique and insecticide. Mathematical Biosciences. 223(1): 12-23

3. Pelaez O, Guzman MG, Kouri G, Perez R, San Martin JL, et al (2004) Dengue 3 epidemic, Havana, 2001. Emerg Infect Dis. 10: 719-722.

4. Richards FJ (1959) A flexible growth function for empirical use. J of Experi Botany. 10: 290-300.

5. Wallinga J, Lipsitch M (2007) How generation intervals shape the relationship between growth rates and reproductive numbers. Proc Biol Sci. 274(1609): 599-604.

6. Hsieh YH, Lee JY, Chang HL (2004) SARS epidemiology. Emerging Infectious Diseases. 10(6):1165-1167.

7. Hsieh YH, Cheng YS (2006) Real-time forecast of multi-wave epidemic outbreaks. Emerging Infectious Diseases. 12(1):122-127.

8. Hsieh YH (2008) Richards Model: A Simple Procedure for Real-time Prediction of outbreak Severity. In Modeling and Dynamics of Infectious Diseases. Zhien Ma Jianhong Wu, Yicang Zhou, eds. Series in Contemporary Applied Mathematics (CAM). 11: 218-239, Beijing, Higher Education Press.

9. Hsieh YH, Ma S (2009) Intervention Measures, Turning Point, and Reproduction Number for Dengue, Singapore, 2005. Am J Trop Med Hyg. 80: 66-71.

10. Hsieh YH, Chen CWS (2009) Turning Points, reproduction number, and Impact

of Climatological events on Multi-Wave Dengue Outbreaks. Trop Med Internat Health. 16(4): 1-11.

11. Hsieh YH (2010) Pandemic Influenza A (H1N1) during Winter Influenza Season in the Southern Hemisphere. Influenza and other Respiratory Viruses. 4(4): 187-197.

12. Hsieh YH, Fisman D, Wu J (2010) Epidemic Modeling in Real Time: 2009 Novel A (H1N1) Influenza Outbreak in Canada. BMC Research Notes. 3: 283.

13. Hsieh YH, Ma S, Valasco-Hernandez J, Lee V, Yen LW (2011a) 2009 Influenza A (H1N1) in Mexico: Initial Outbreak, Turning Points, and Reproduction Number. PLoS ONE. 6(8): e23853.

14. Hsieh YH, Cheng KF, Chao DY, Wu TN, Li TC, et al (2011b) Transmissibility and Temporal Changes of 2009 pH1N1 Pandemic during Summer and Fall/Winter Waves. BMC Inf Diseases. 11: 332.

15. Alvarez M, Rodriguez-Roche R, Bernardo L, Vazquez S, Morier L, et al (2006) Dengue hemorrhagic fever caused by sequential dengue 1-3 virus infections over a long time interval: Havana epidemic, 2001-2002. Am J Trop Med Hyg. 75: 1113-1117.

16. Favier C, Degallier N, Rosa-Freitas MG (2006) Early determination of the reproductive number for vector-borne diseases: the case of dengue in Brazil. Tropical Medicine and International Health.11: 332-340.

17. Pielke RA, Rubiera J, Landsea C, Fernández ML, Klein R (2003) Hurricane Vulnerability in Latin America and the Caribbean: Normalized Damage and Loss Potentials. Nat Hazards Rev. 4(3): 101-114.

18. http://en.wikipedia.org/wiki/List_of_wettest_tropical_cyclones_by_country#Cuba

19. Instituto Nacional de Recursos Hidráulicos (2003) Lluvias intensas observadas y grandes inundaciones reportadas (in Spanish).
20. Chowell G, Sanchez F (2006) Climate-based descriptive model of dengue fever: the 2002 epidemic in Colima, Mexico. Journal of Environmental Health. 68: 40-44.
21. Wu PC, Guo HR, Lung SC, Lin CY, Su HJ (2007) Weather as an effective predictor for occurrence of dengue fever in Taiwan. Acta Tropica. 103: 50-57.
22. Pan American Health Organization (1994) Dengue and Dengue Hemorrhagic Fever in the Americas: Guidelines for Prevention and Control. 548 p.

Figure Legends

Figure 1. Richards model fit for 2001 dengue outbreak in (1a) Playa, (1b) Plaza, (1c) Central Havana, (1d) Old Havana, and (1e) all of Havana City.

Figure 2. Timelines for 2001 dengue outbreak (with turning points) in: (2a) Playa, Plaza, Central Havana, Old Havana; (2b) Diez de Octubre, Cerro, Marianao, Lisa, Boyeros, and Arroyo Naranjo; (2c) Regla, Havana de Este, Guanabacoa, SMP, and Havana City total.

Table 1a. Estimated Richards model parameters values with 95% confidence intervals (in parenthesis) for all regions other than Regla, Habana de Este, Guanabacoa, Arroyo Naranjo, SMP, and Cotorro. Note that the week in which the true turning point for each wave occurred is t_i weeks after the first week of the wave.

Region	**Week**	**Turning point t_i**	**Growth rate r**	**Case number K**	**R_0**
Playa	3 - 22	14.30 (13.99, 14.61)	0.393 (0.364, 0.422)	1601 (1564, 1638)	3.848 (3.821, 3.874)
	22 - 30	2.46 (1.26, 3.66)	0.019 (0.014, 0.023)	1764 (1706, 1822)	1.066 (1.062, 1.069)
	30 - 37	4.38 (4.14, 4.62)	0.274 (0.247, 0.301)	79 (76, 81)	2.558 (2.539, 2.557)
Plaza	12 - 23	7.72 (7.16, 8.27)	0.660 (0.145, 1.175)	845 (627, 1064)	9.611 (9.172, 10.049)
	23 - 32	3.76 (3.21, 4.30)	0.106 (0.092, 0.119)	1389 (1336, 1442)	1.436 (1.426, 1.447)
	32 - 39	1.80 (1.09, 2.52)	0.025 (0.018, 0.031)	1468 (1459, 1476)	1.088 (1.083, 1.093)
C. Hab	11 - 23	9.78 (8.90, 10.65)	0.747 (0.475, 1.018)	613 (534, 693)	12.937 (12.702, 13.172)
	23 - 31	3.63 (2.29, 4.96)	0.137 (0.093, 0.182)	1366 (1184, 1549)	1.601 (1.306, 1.895)
	31 - 38	2.58 (2.02, 3.15)	0.044 (0.037, 0.052)	1564 (1543, 1585)	1.164 (0.870, 1.458)
Old Havana	12 - 23	8.35 (7.54, 9.16)	0.655 (0.434, 0.876)	167 (151, 184)	9.441 (9.253, 9.628)
	23 - 40	11.68 (11.33, 12.02)	0.122 (0.114, 0.129)	817 (800, 834)	1.518 (1.511, 1.525)
Diez de Octubre	11 – 24	9.90 (9.53, 10.26)	0.327 (0.285, 0.370)	362 (345, 379)	3.070 (3.033, 3.108)
	24 – 31	4.60 (4.11, 5.09)	0.157 (0.133, 0.180)	848 (806, 891)	1.711 (1.694, 1.728)
	31 - 38	2.79 (0.86, 4.73)	0.636 (0.228, 1.043)	119 (109, 129)	8.842 (8.555, 9.130)

Cerro	17 - 22	4.06 (4.03, 4.10)	0.483 (0.470, 0.496)	375 (369, 381)	5.229 (5.223, 5.235)
	22 - 30	2.58 (0.29, 4.87)	0.195 (0.056, 0.335)	850 (763, 937)	1.954 (1.848, 2.060)
	30 - 39	5.92 (4.71, 7.14)	0.030 (0.023, 0.037)	1009 (985, 1033)	1.107 (1.101, 1.112)
Marianao	8 - 23	12.70 (12.60, 12.79)	0.581 (0.556, 0.605	627 (618, 636)	7.320 (7.298, 7.342)
	23 - 32	1.70 (0.53, 2.87)	0.122 (0.088, 0.156)	1062 (1037, 1088)	1.518 (1.490, 1.545)
	32 - 37	3.38 (2.37, 4.39)	0.028 (0.018, 0.038)	1147 (1130, 1165)	1.100 (1.095, 1.105)
Lisa	13 - 23	7.69 (7.45, 7.94)	0.760 (0.674, 0.847)	249 (241, 257)	13.555 (13.483, 13.627)
	23 - 32	4.40 (3.63, 5.17)	0.081 (0.066, 0.097)	426 (406, 445)	1.322 (1.310, 1.334)
	32 - 38	1.91 (1.06, 2.75)	0.034 (0.023, 0.044)	478 (472, 483)	1.122 (1.116, 1.129)
Boyeros	14 - 23	6.74 (5.07, 8.41)	1.199 (0.428, 1.971)	339 (290, 387)	61.062 (60.444, 61.680)
	23 - 31	2.99 (1.82, 4.17)	0.230 (0.092, 0.367)	896 (766, 1025)	2.197 (2.092, 2.302)
	31 - 39	1.08 (0.09, 2.06)	0.038 (0.029, 0.048)	960 (946, 973)	1.140 (1.133, 1.148)

Table 1b. Estimated Richards model parameters values with 95% confidence intervals (in parenthesis) for Regla, Habana de Este, Guanabacoa, Arroyo Naranjo, and SMP. Note that the week in which the true turning point for each wave occurred is ti weeks after the first week of the wave.

Region	Week	Turning point t_i	Growth rate r	Case number K	R_0
Regla	21 - 31	5.11 (4.38, 5.84)	0.420 (0.181, 0.659)	188 (162, 214)	4.215 (4.017, 4.413)
	31 - 38	1.95 (1.22, 2.68)	0.058 (0.042, 0..075)	208 (206, 211)	1.221 (1.209, 1.233)
Havana del. Este	14 - 24	7.71 (4.86, 10.55)	0.841 (0.203, 1.479)	158 (113, 204)	17.882 (17.353, 18.410)
	24 - 31	4.81 (4.60, 5.01)	0.210 (0.196, 0.223)	437 (423,451)	2.052 (2.042, 2.061)
	31 - 39	2.32 (1.43, 3.21)	0.085 (0.062, 0.108)	633 (620, 646)	1.340 (1.322, 1.357)
Guanabacoa	16 - 31	8.81 (8.08, 9.54)	0.490 (0.201, 0.780)	199 (177, 220)	5.373 (5.112, 5.633)
	31 - 37	2.51 (1.18, 3.83)	0.048 (0.029, 0.067)	234 (217, 252)	1.178 (1.166, 1.190)
Arroyo Naranjo	8 - 26	13.05 (12.18, 13.92)	0.198 (0.163, 0.233)	625 (576, 675)	1.974 (1.941, 2.006)
	26 - 31	3.32 (2.82, 3.83)	0.066 (0.055, 0.076)	833 (816, 850)	1.253 (1.248, 1.257)
	31 - 38	3.49 (2.60, 4.38)	0.028 (0.021, 0.035)	954 (941, 968)	1.102 (1.097, 1.106)
SMP	7 - 23	13.30 (12.99, 13.61)	0.460 (0.403, 0.516)	74 (71, 78)	4.836 (4.785, 4.887)
	23 - 31	6.15 (5.60, 6.69)	0.256 (0.209, 0.302)	408 (372, 445)	2.405 (2.369, 2.440)
	31 - 39	4.08 (3.48, 4.67)	0.082 (0.068, 0.097)	616 (603, 629)	1.326 (1.315, 1.337)
Havana City	3 - 23	17.54 (17.43, 17.66)	0.316 (0.305, 0.327)	5933 (5771, 6095)	2.956 (2.945, 2.966)

Total	23 - 31	4.48 (4.14, 4.81)	0.095 (0.087, 0.103)	11003 (10578, 11418)	1.385 (1.379, 1.391)
	31 - 40	3.02 (2.66, 3.37)	0.037 (0.034, 0.041)	12879 (12820, 12938)	1.137 (1.134, 1.140)