HUMANOS, MOSQUITOS Y AMBIENTE: UN MODELO PARA EL DENGUE

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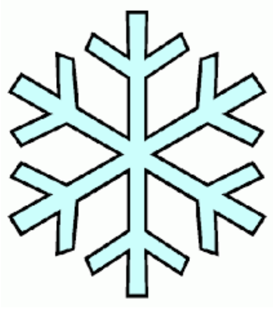
Centro Atómico Bariloche - CONICET

TREFEMAC 2019, 24 al 26 de abril, San Luis

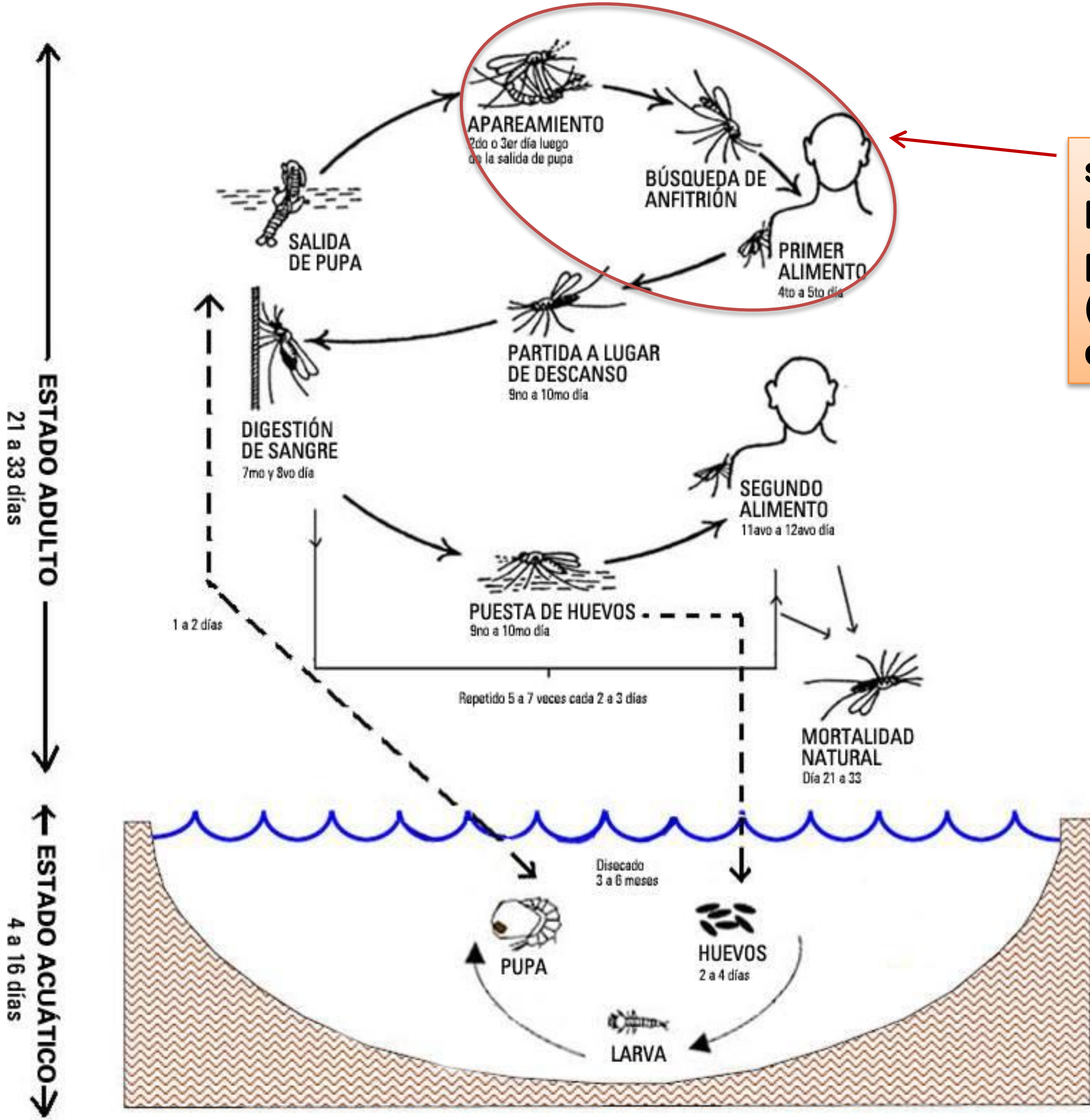
Mosquito transmisor del dengue

Aedes aegypti



Ciclo del mosquito

variables ambientales



sólo las hembras pican (transmisión del virus)

larvas:

compiten por comida

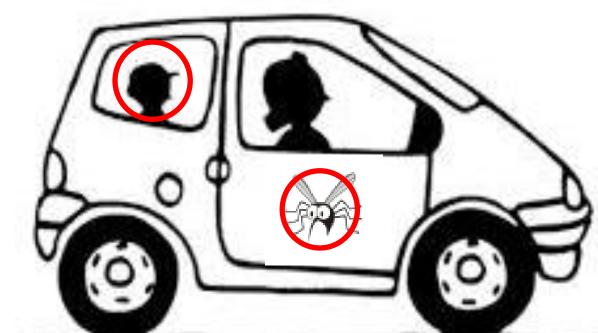
reducen eclosión de huevos

Aedes aegypti y los hábitos domésticos humanos

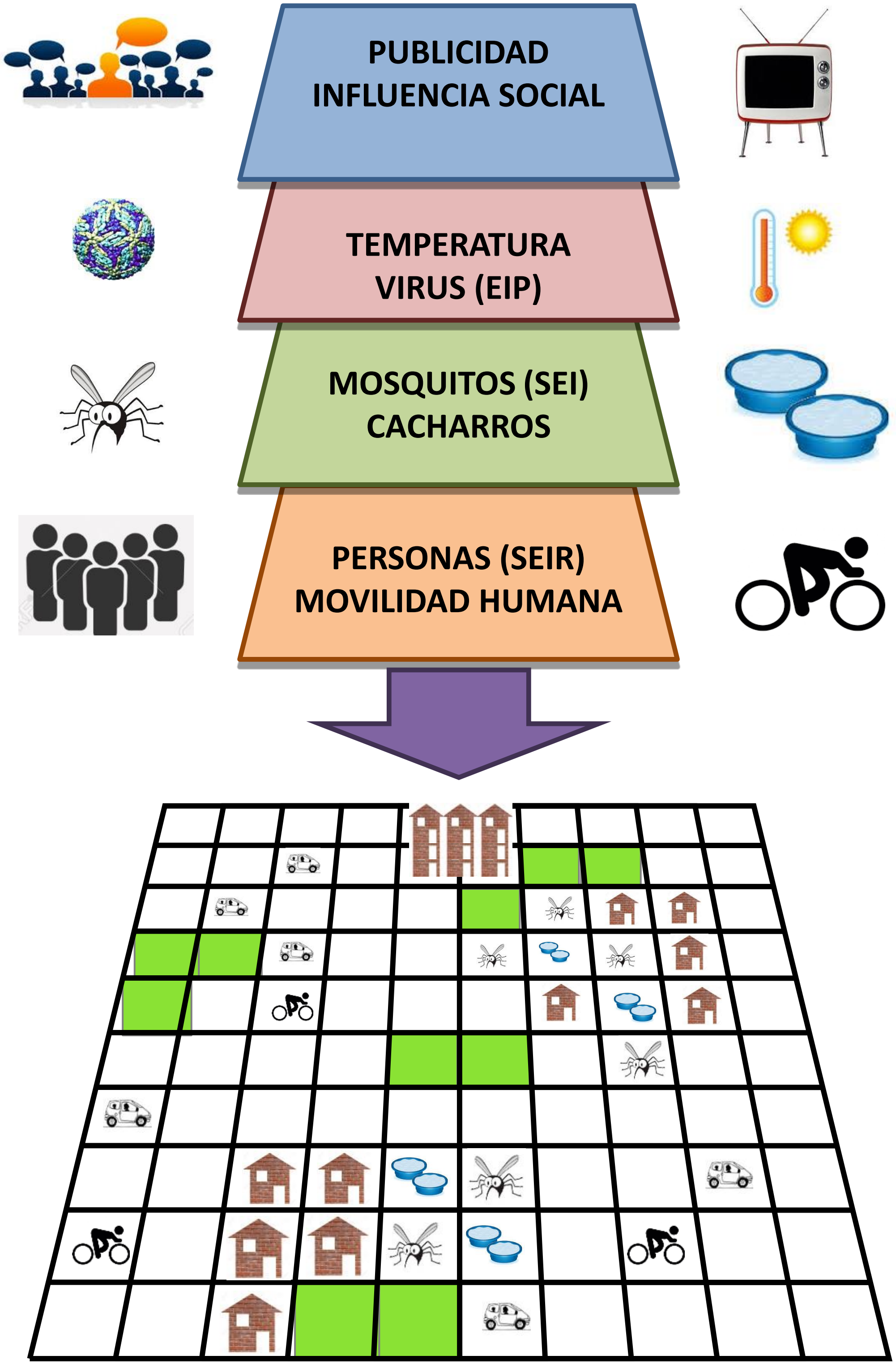
Campañas de prevención

SIN AGUA
NO HAY CRIADEROS
SIN CRIADEROS
NO HAY MOSQUITOS
SIN MOSQUITOS
NO HAY DENGUE

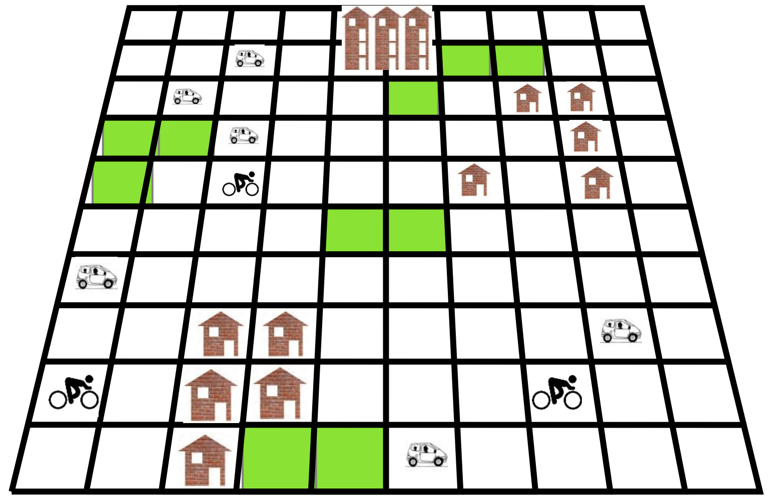
Mosquitos y comportamiento social



Nuestro modelo

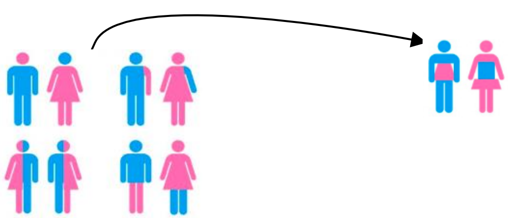


Humanos



movilidad en la grilla + **modelo epidemiológico**

Traslado con probabilidad 1/R



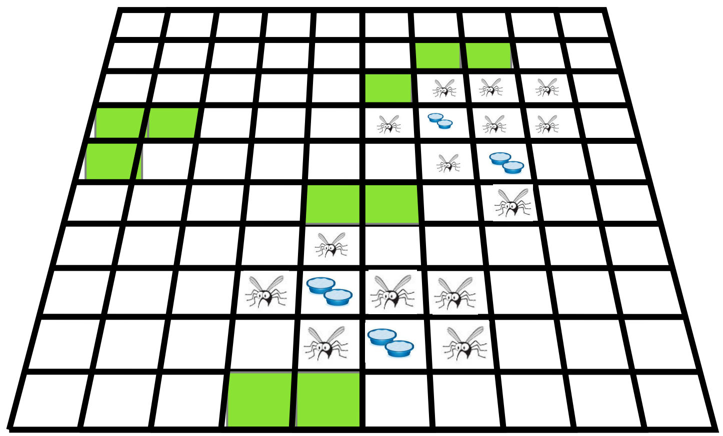
SEIR

Desarrollo y Transmisión del virus

+

Conductas sociales

Mosquitas



modelo de agentes + **modelo epidemiológico**

Crecimiento de la población
+
Estrategias de control
+
Temperatura

SEI
Desarrollo y Transmisión del virus
+
Temperatura

Modelo epidemiológico para humanos

$S_H \rightarrow E_H \rightarrow I_H \rightarrow R_H$

P_{IH}

Picaduras:
- Eventos independientes
- Tasa constante

Distribución de Poisson

Probabilidad de que un humano se infecte

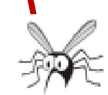
IIP

Período de incubación intrínseco (7d)

IRP

Período de recuperación (8d)

$$P_{IH} = 1 - \exp(-b\ \beta_{HM}\ I_M / Po_M)$$



b= n° picaduras × día × mosquito =2

β_{HM}= prob. de infectarse × picadura= 0.2

I_M=n° mosquitos infectivos × celda

Po_M = población de mosquitos

Modelo epidemiológico para las mosquitas

$S_M \longrightarrow E_M \longrightarrow I_M$

P_{IM}

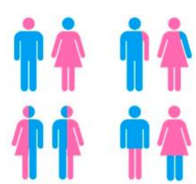
EIP

Probabilidad de que una mosquita se infecte

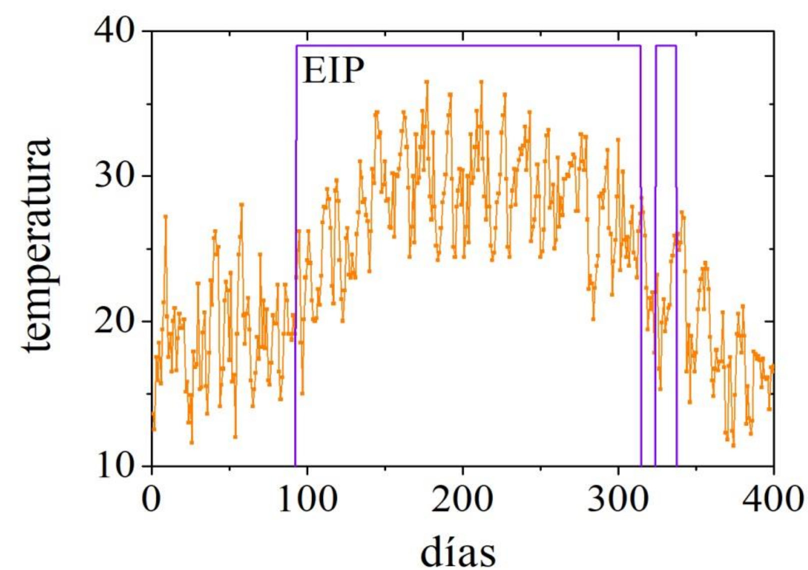
Período de Incubación Extrínseco del virus en la mosquita

El virus se incuba en la mosquita
(7 a 21 días según T)

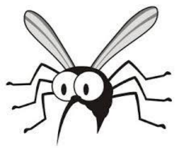
$$P_{IM} = 1 - \exp(-b\ \beta_{MH}\ I_H / Po_H)$$



b= n° picaduras × día × mosq= 2
I_H = n° humanos × celda
β_{MH}= prob. de infectarse × picar=0.17
Po_H = poblac. humanos total



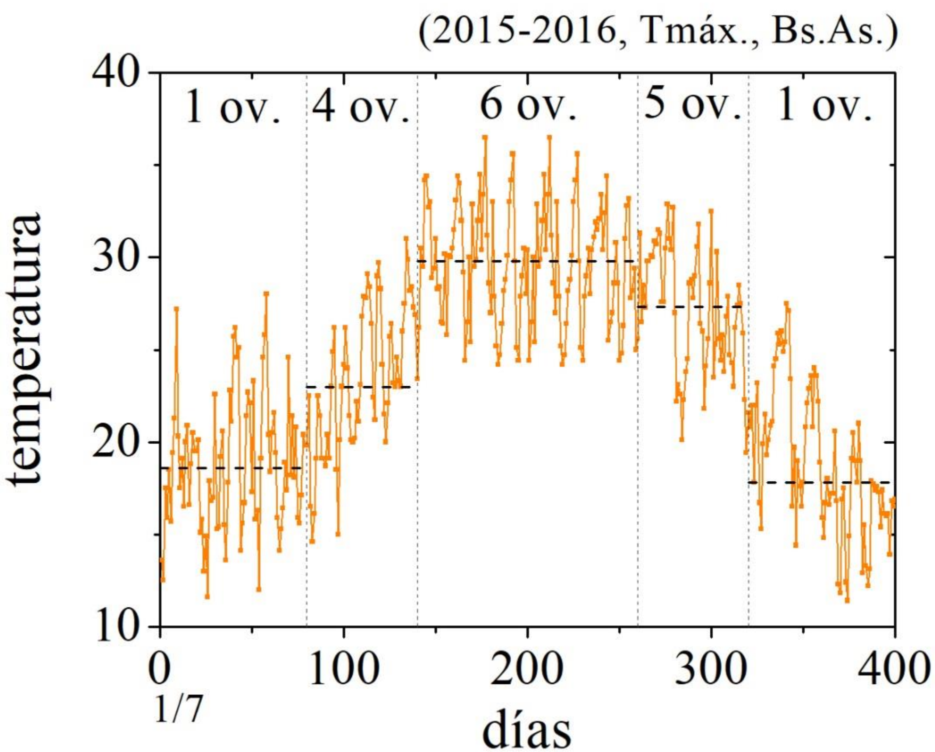
Mosquitas: simulaciones con el modelo de agentes



= estado | tacho | edad actual | días de vida | etapa acuática

Los parámetros vitales de cada nuevo individuo se toman al azar de las distribuciones de probabilidad obtenidas de los datos.

Temperatura y oviposición

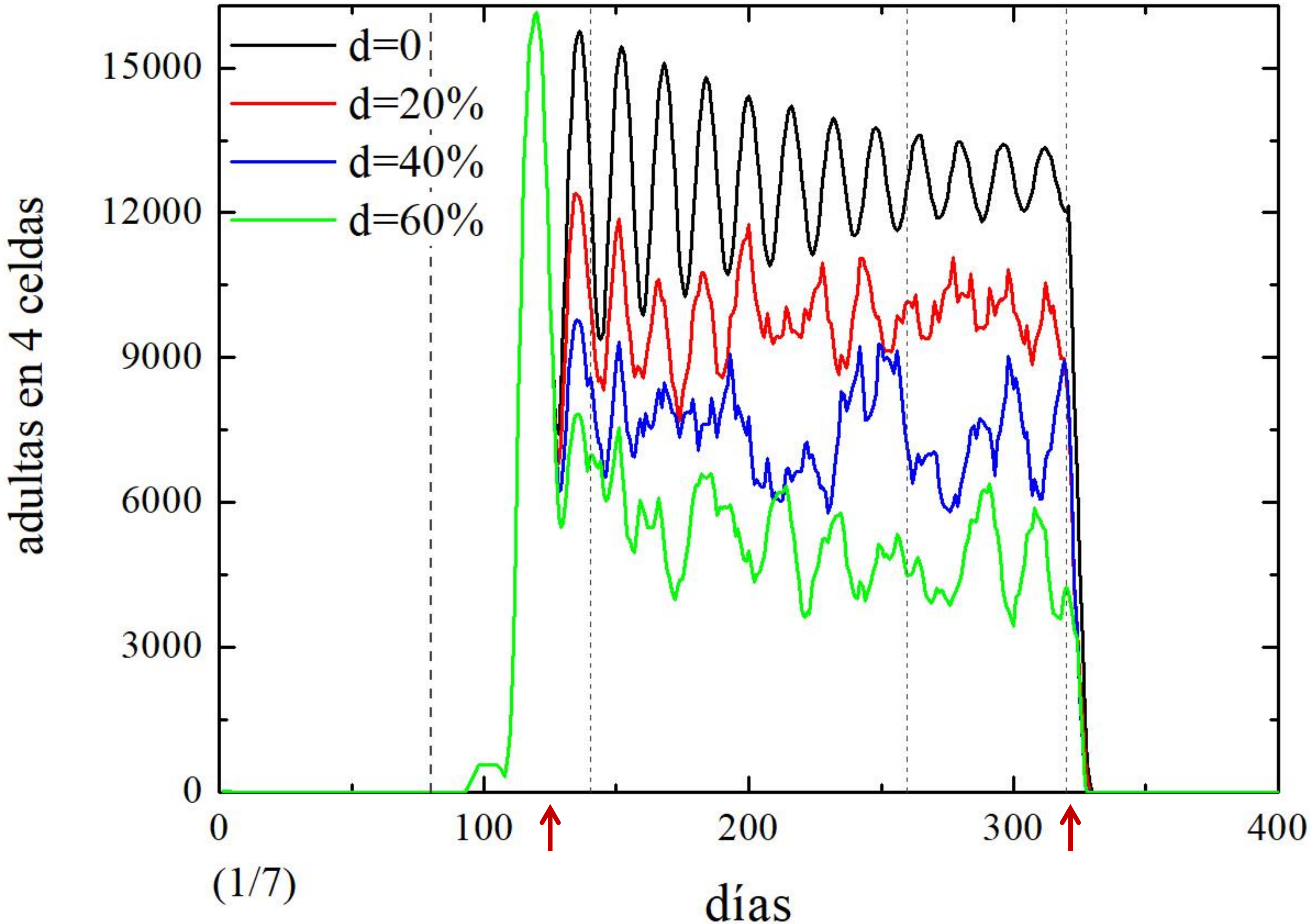


Otero, Solari, Dorso, *et al.*

- **Saturación de tachos (800 huevos).**
- **Mortalidad de todas las etapas.**
- **Transferencia de adultas a otros tachos.**
- **Hibernación de huevos.**
- **Número variable de huevos por puesta.**
- **Descacharrado semanal (parcial o total).**

CI: 1 adulta por tacho (5 tachos por celda)

Mosquitas - agentes: efecto del descacharrado



El descacharrado semanal durante el período más cálido disminuye la cantidad de mosquitas y desdibuja las oscilaciones.

Mosquitas adultas obtenidas diariamente con el modelo de agentes

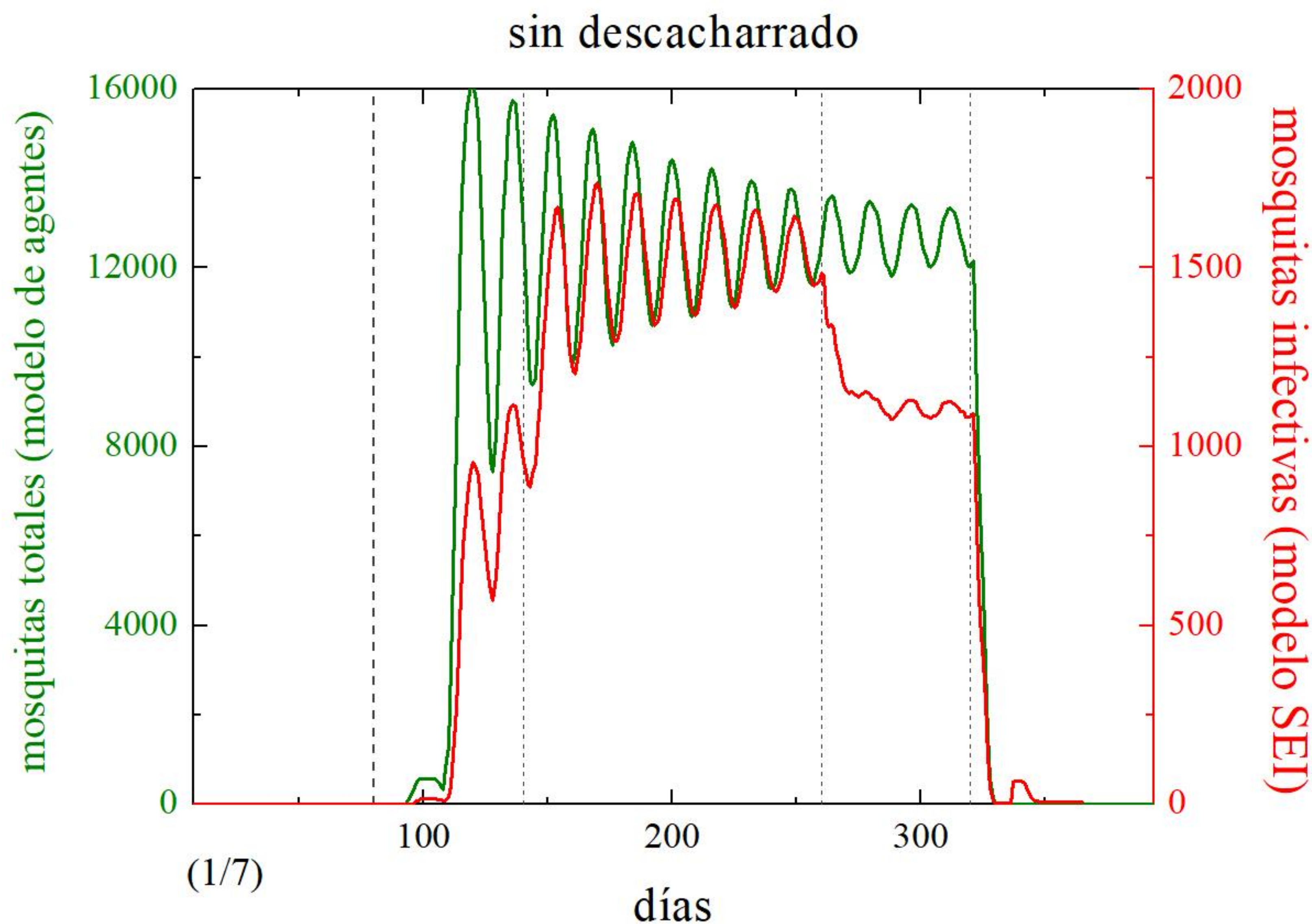
↓

Mosquitas susceptibles del modelo epidemiológico

↓

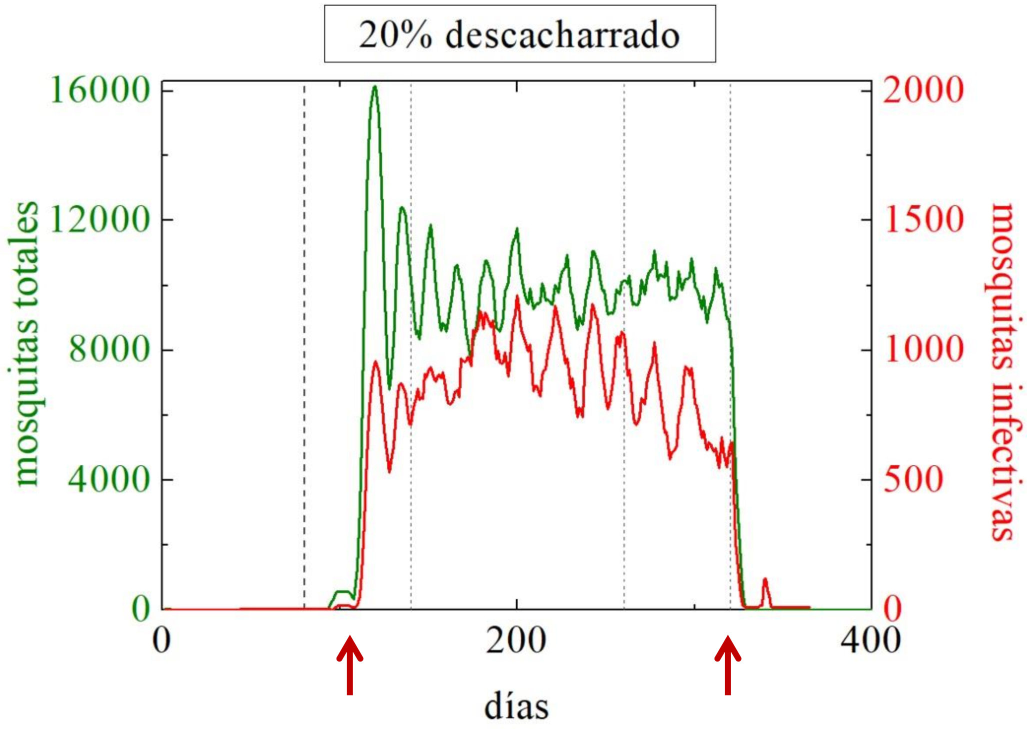
Mosquitas infectivas del modelo epidemiológico

Mosquitas SEI: efecto de la temperatura en el EIP



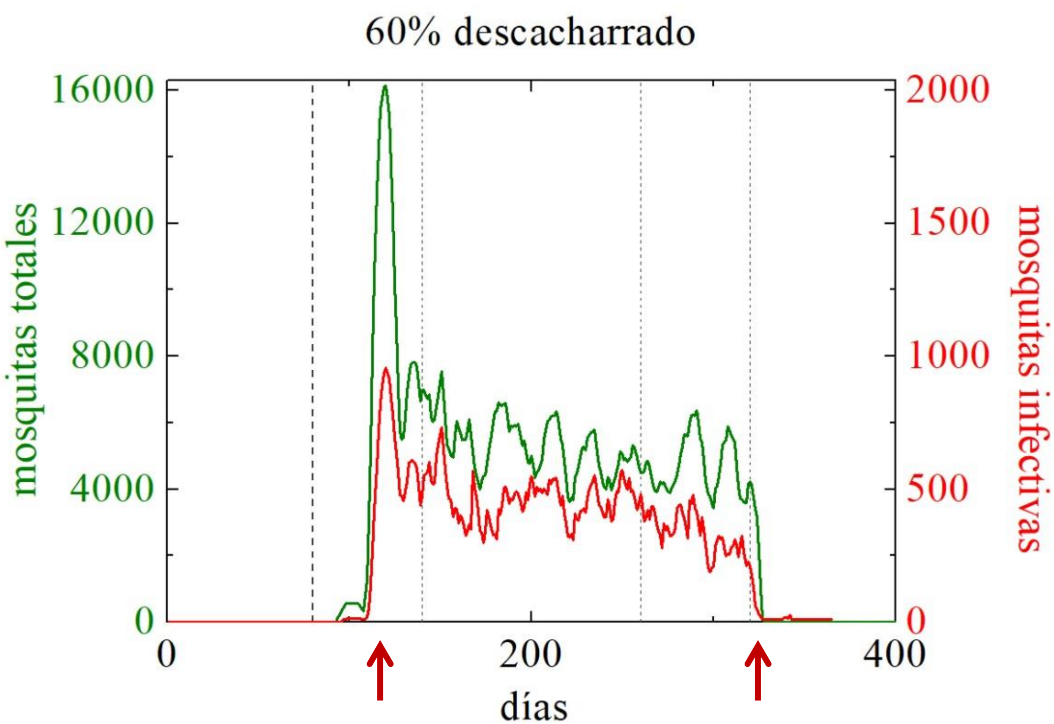
La temperatura, a través del período de incubación del virus (EIP), regula la población de mosquitas infectivas.
Esto es especialmente claro en las etapas de temperaturas moderadas.

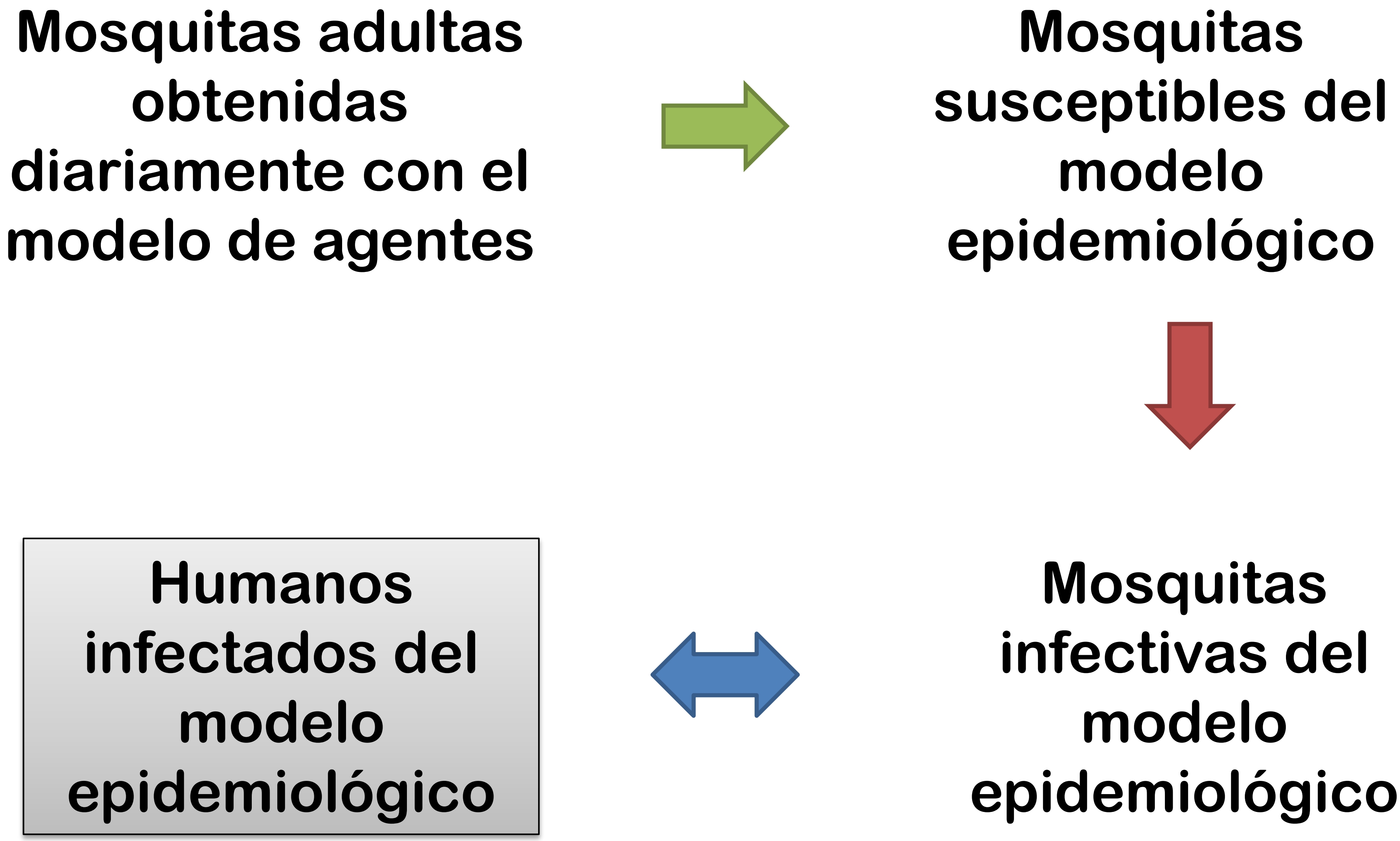
Descacharrado y Mosquitas SEI



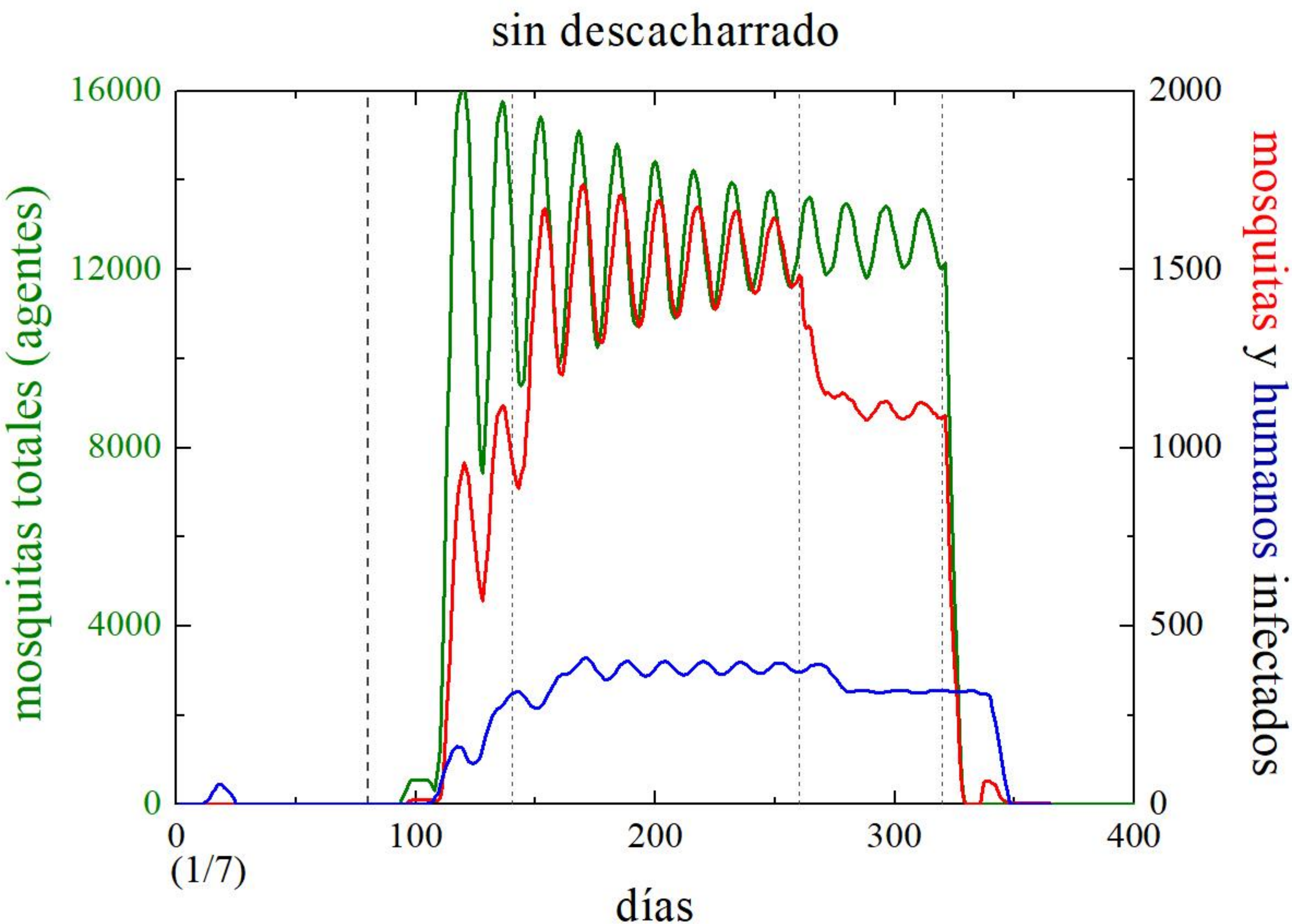
El descacharrado semanal disminuye la población de mosquitas infectivas y suaviza el efecto de la temperatura.

El pico inicial aparece en la etapa previa al descacharrado, luego de la maduración del virus en el mosquito.

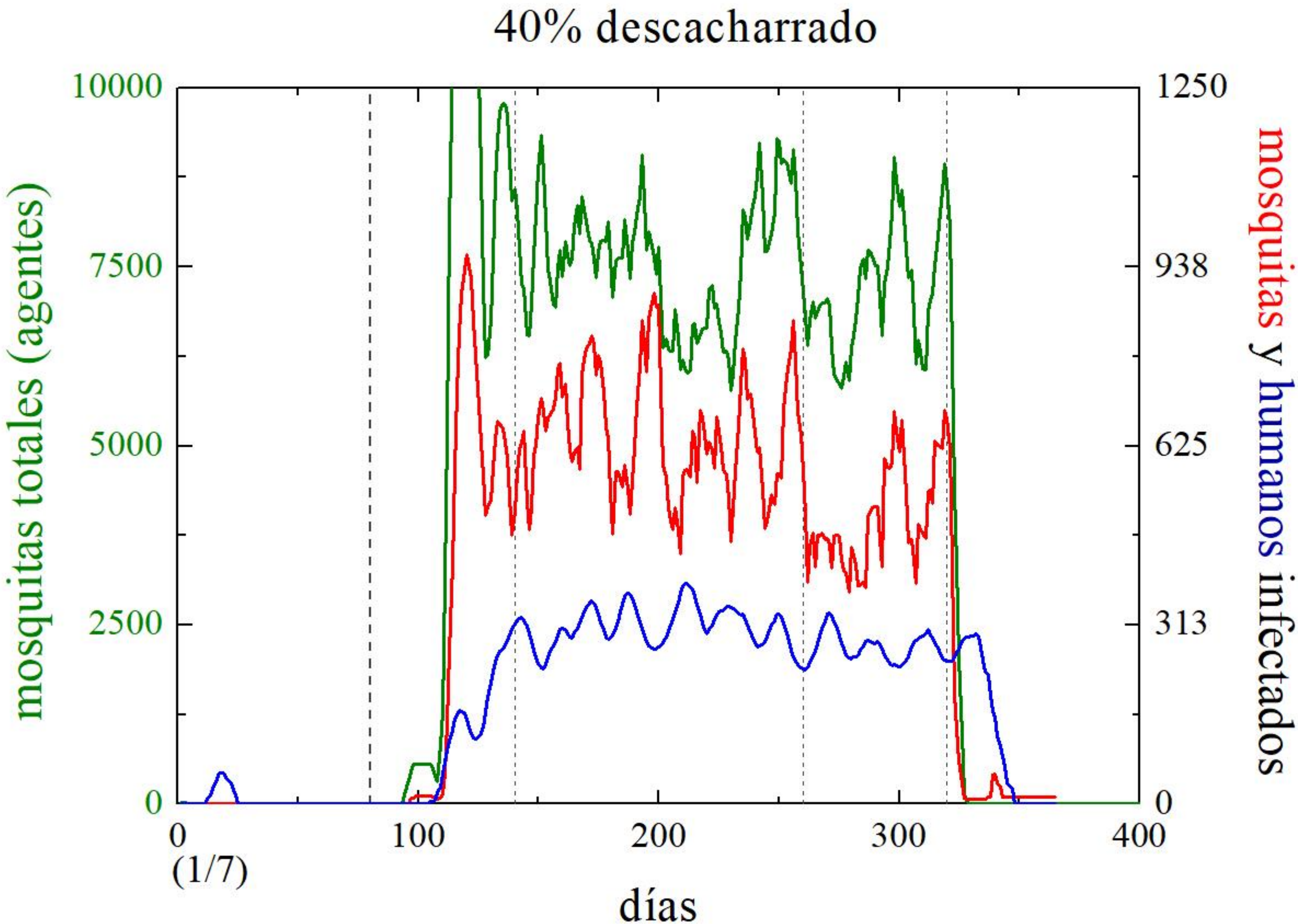



Mosquitas adultas obtenidas diariamente con el modelo de agentes
Mosquitas susceptibles del modelo epidemiológico
Mosquitas infectivas del modelo epidemiológico
Humanos infectados del modelo epidemiológico

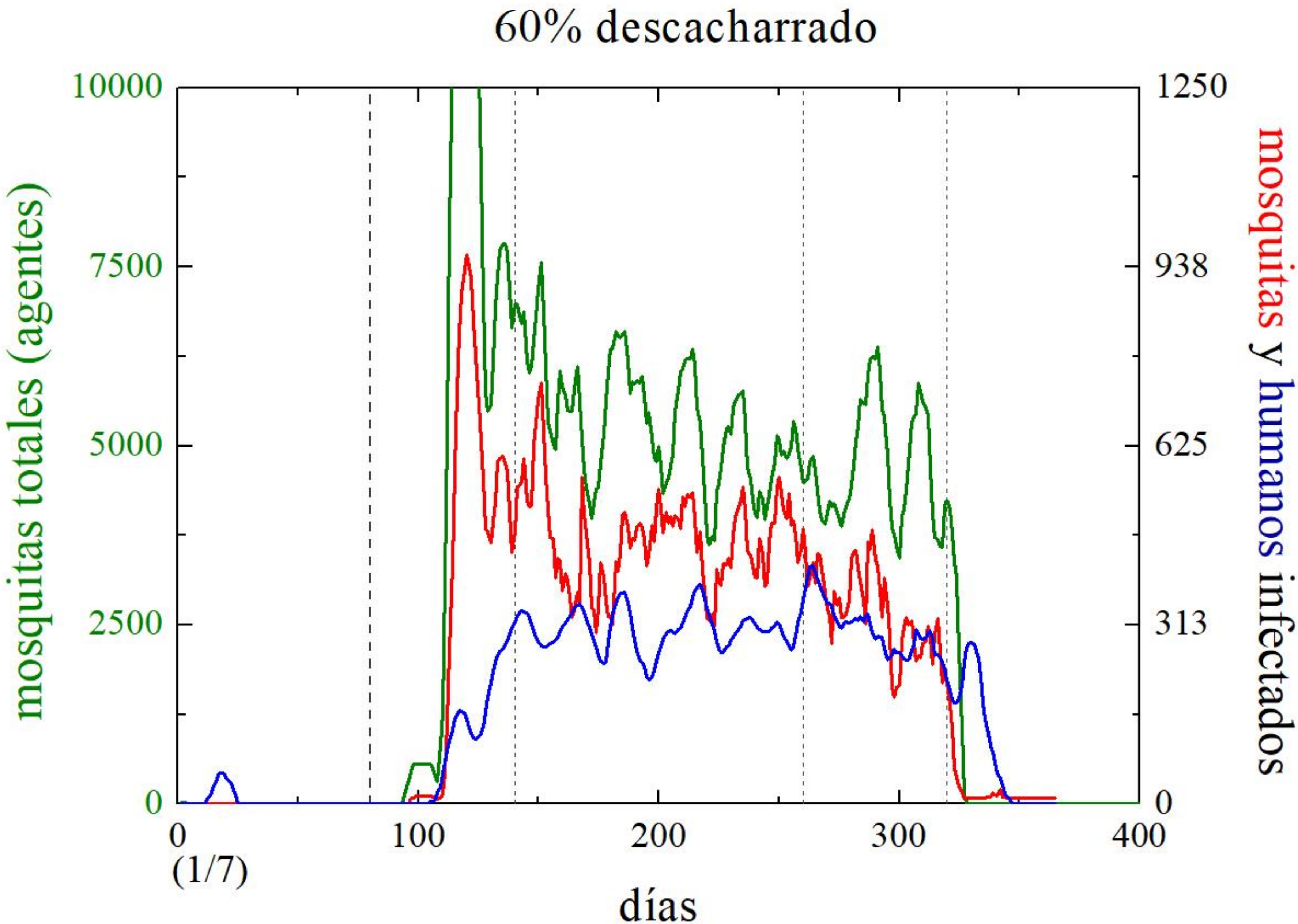
Mosquitas agentes, mosquitas SEI y humanos



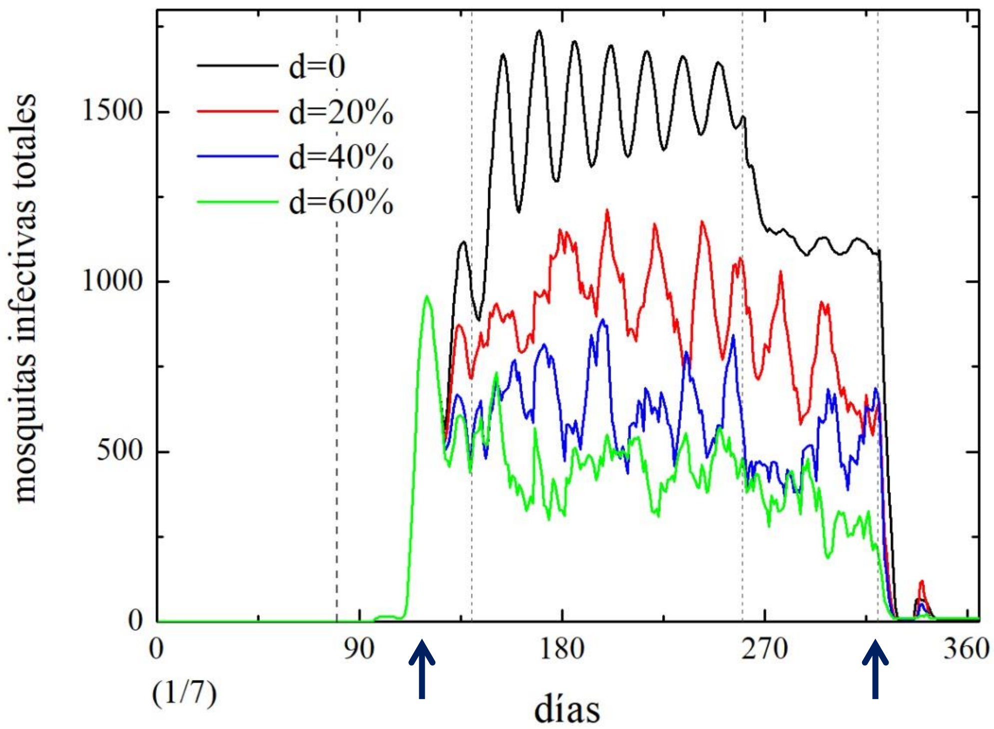
Mosquitas agentes, mosquitas SEI y humanos



Mosquitas agentes, mosquitas SEI y humanos

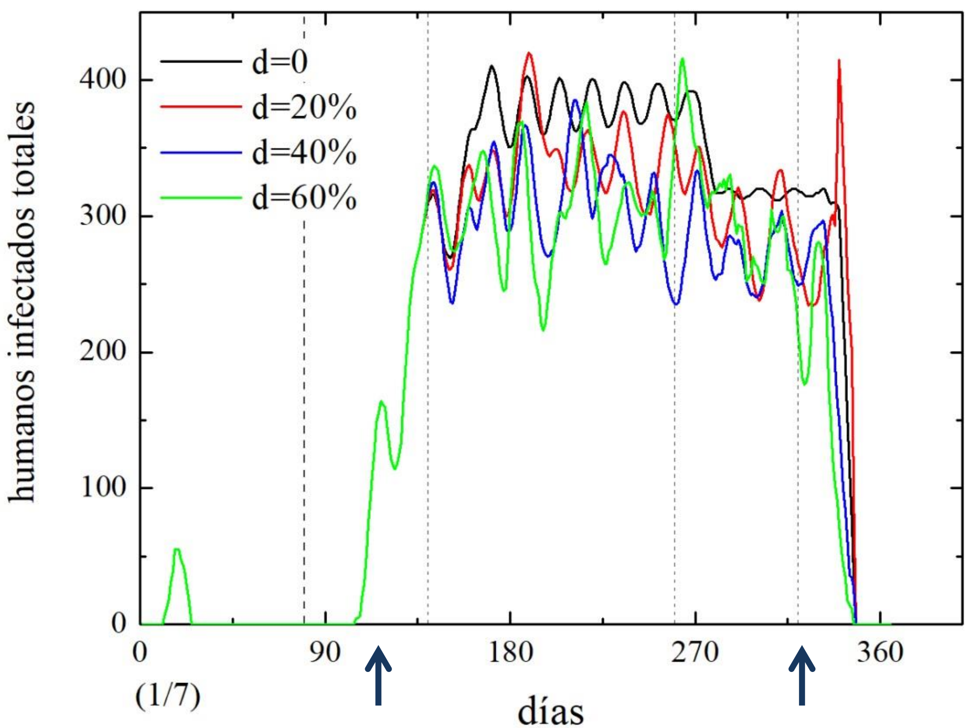


Descacharrado y modelos epidemiológicos



Las mosquitas infectivas son muy sensibles al descacharrado

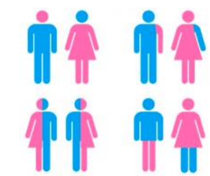
Los humanos infectados no tanto

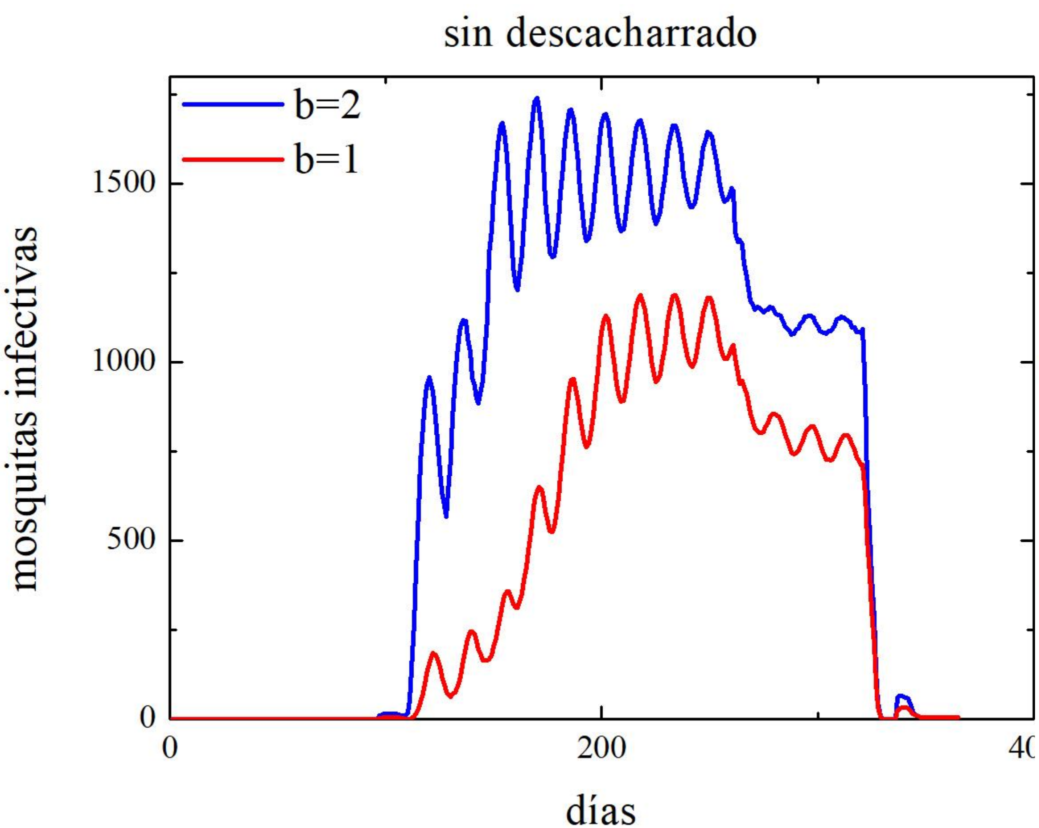


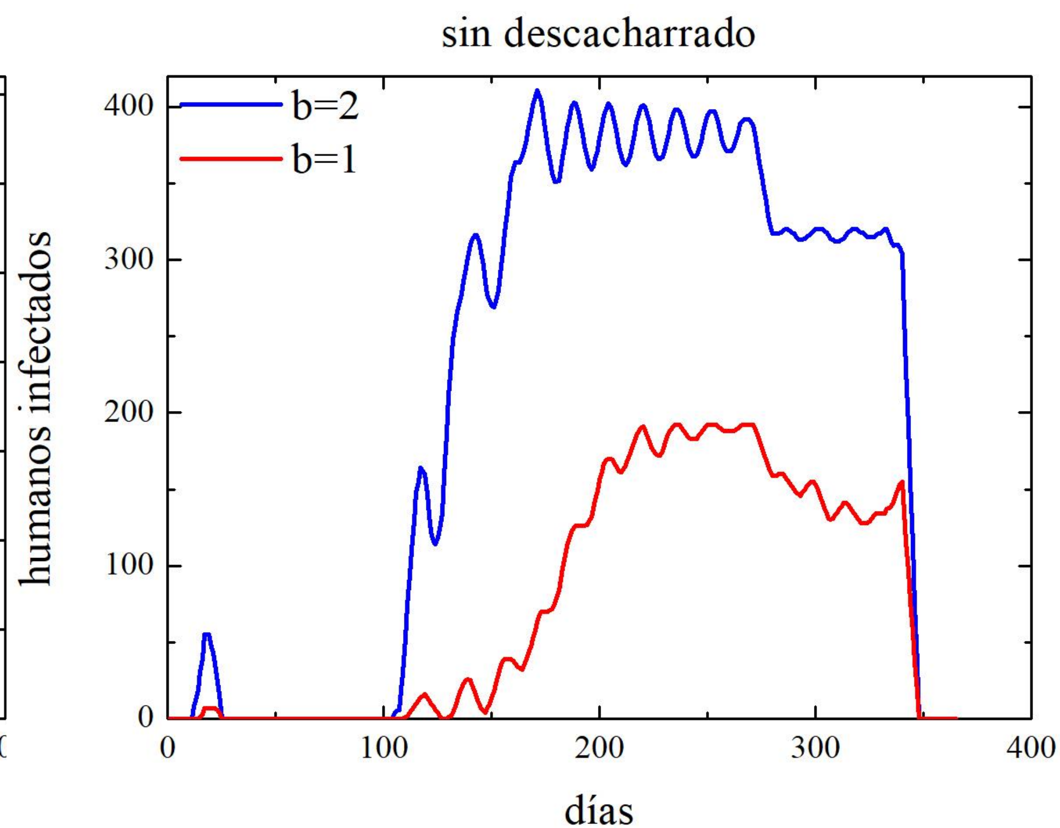
Repelentes en los modelos epidemiológicos: cambiando el “b”

$$P_{IH} = 1 - \exp(-b\ \beta_{HM}\ I_M / Po_M)$$

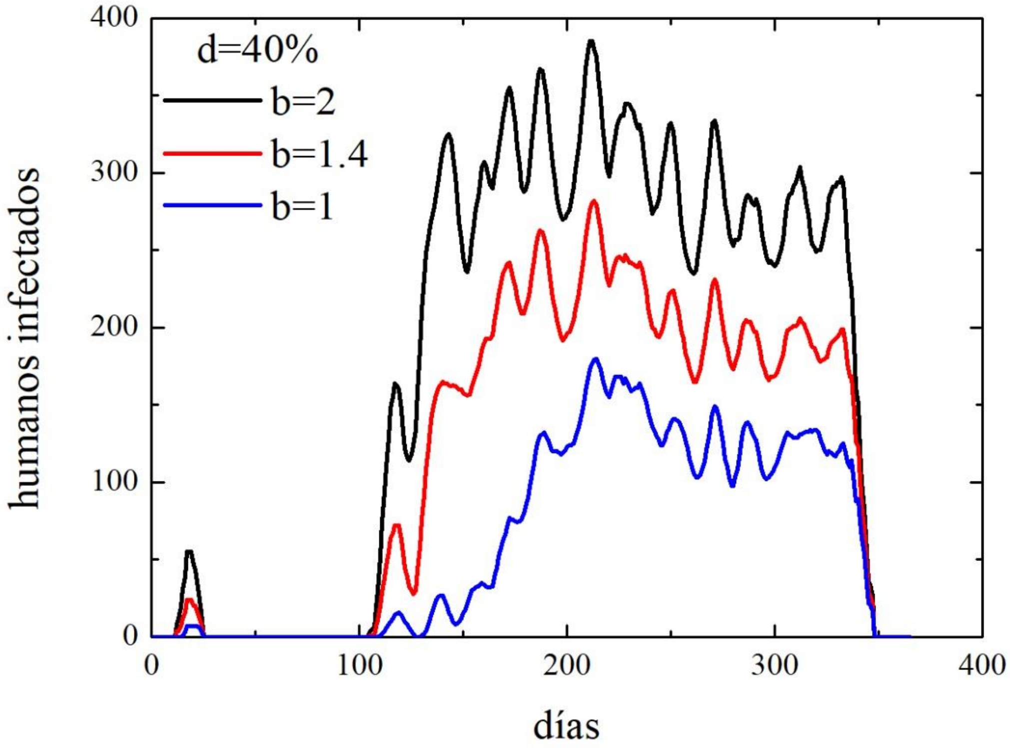
$$P_{IM} = 1 - \exp(-b\ \beta_{MH}\ I_H / Po_H)$$





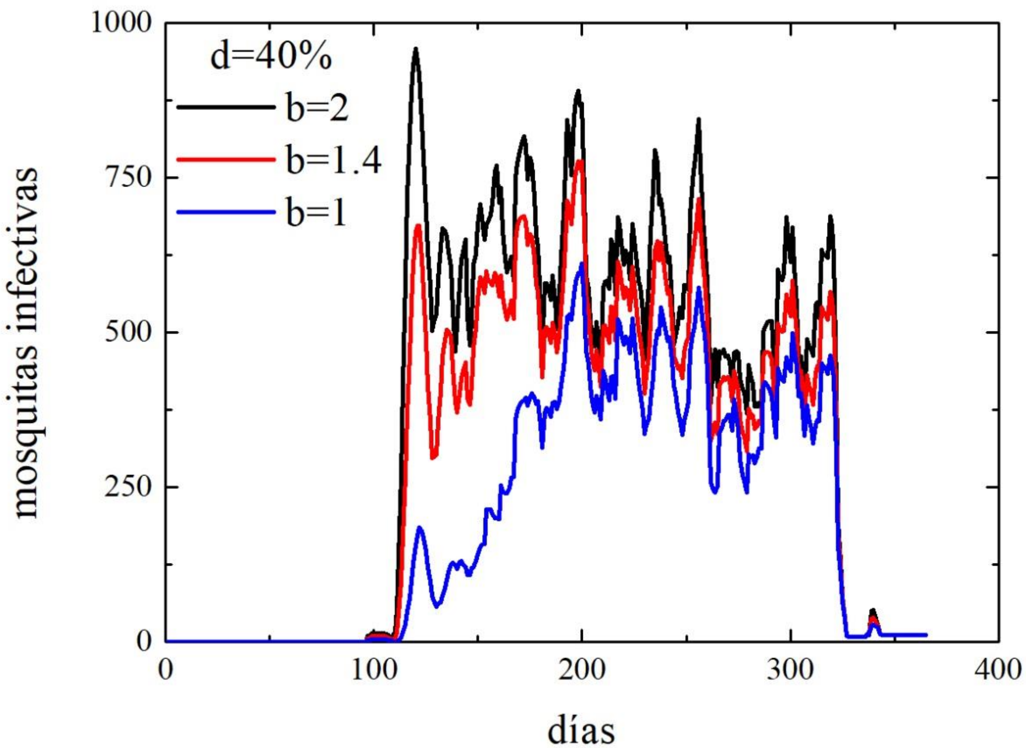


Repelente y descacharrado: dos intervenciones humanas

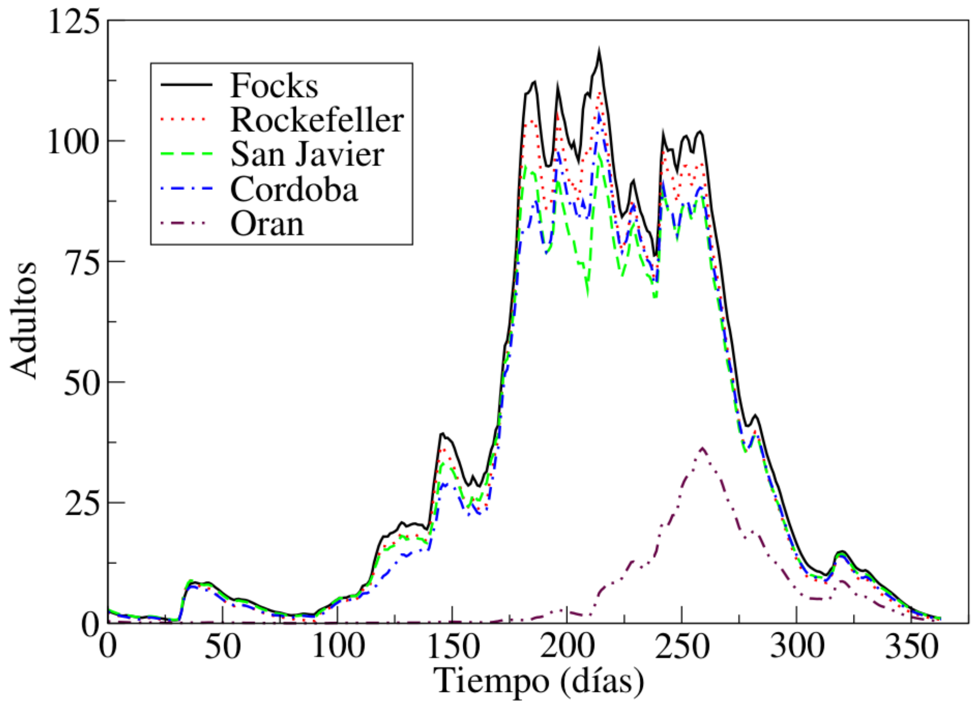


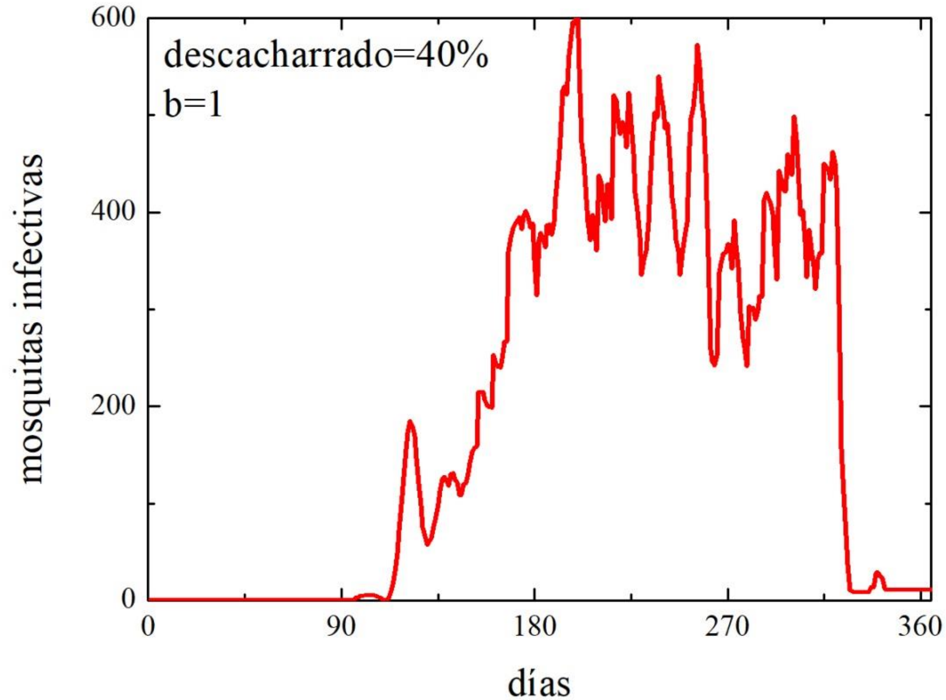
Los humanos infectados son muy sensibles al repelente

Las mosquitas infectivas no tanto

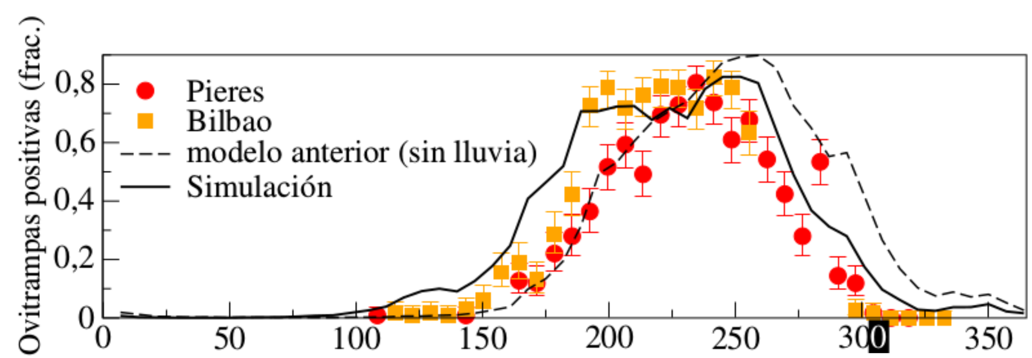


¿Cuán lejos estamos de la realidad?

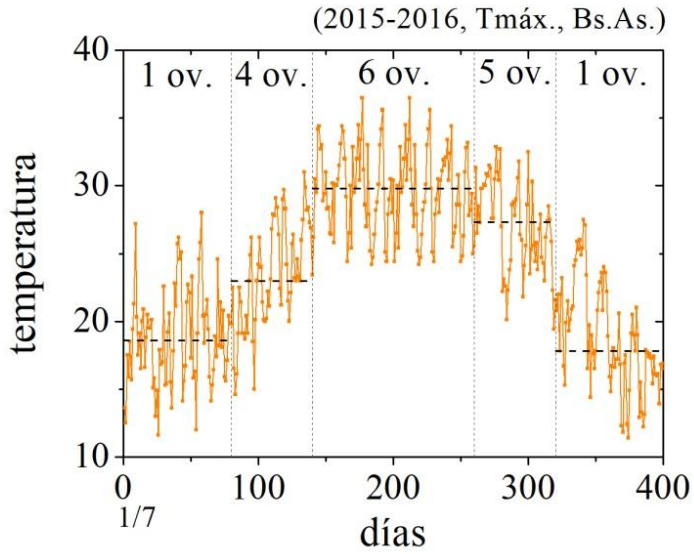


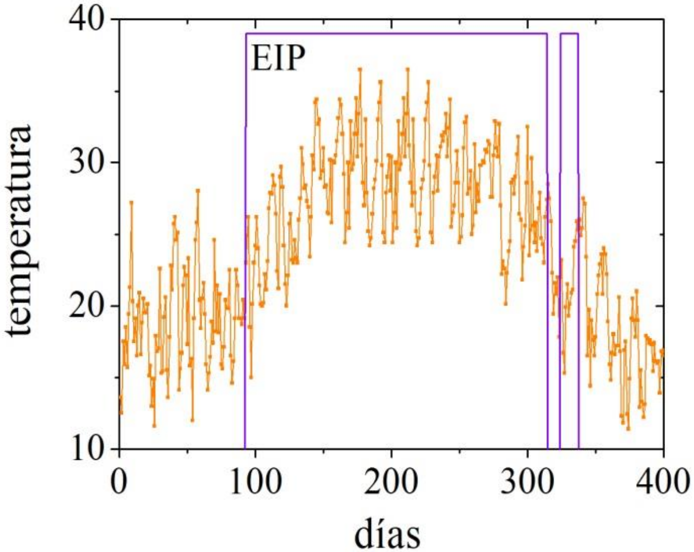


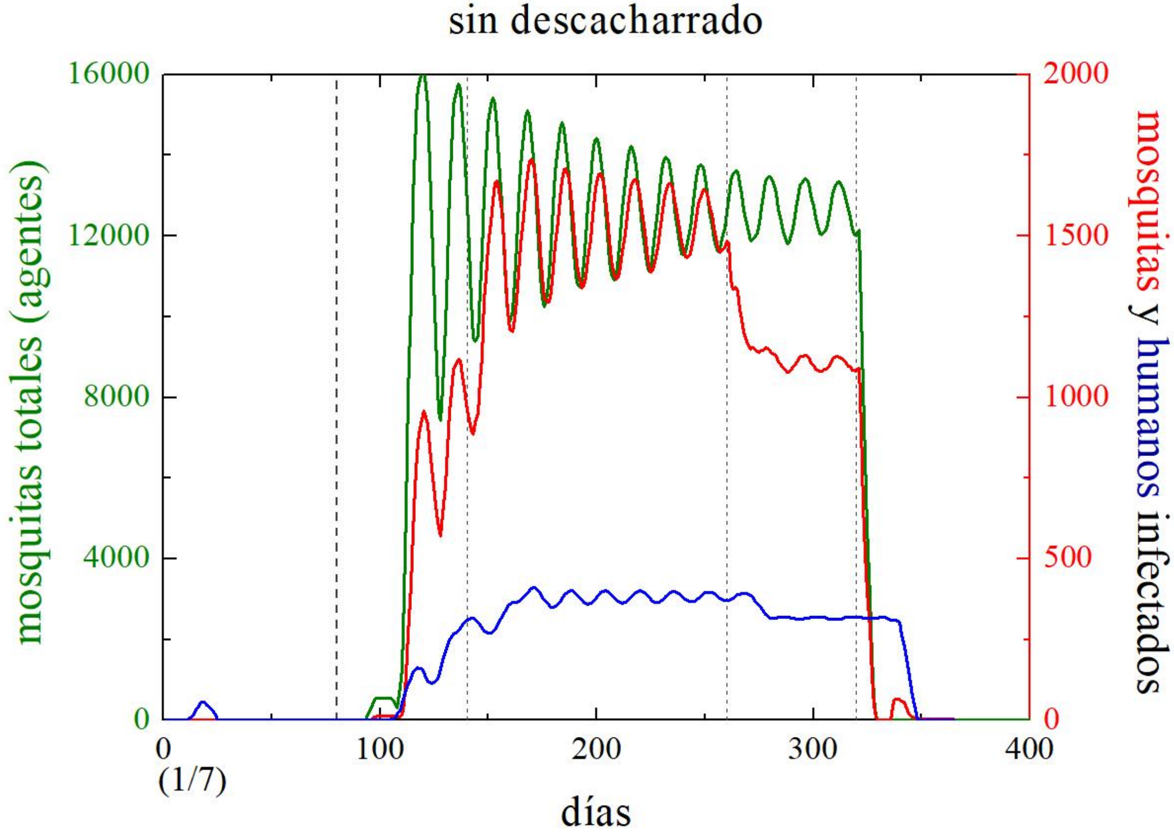
Simulaciones incluyendo competencia intraespecífica, comida, lluvia, etc. con datos de ovitrampas.
Tesis doctoral de Victoria Romeo Aznar (U.B.A, 2015)



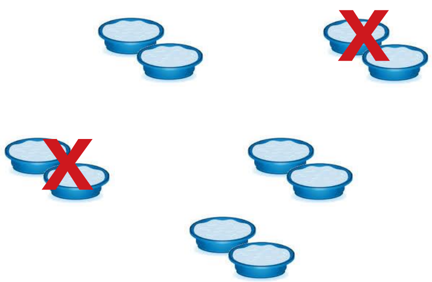
Conclusiones

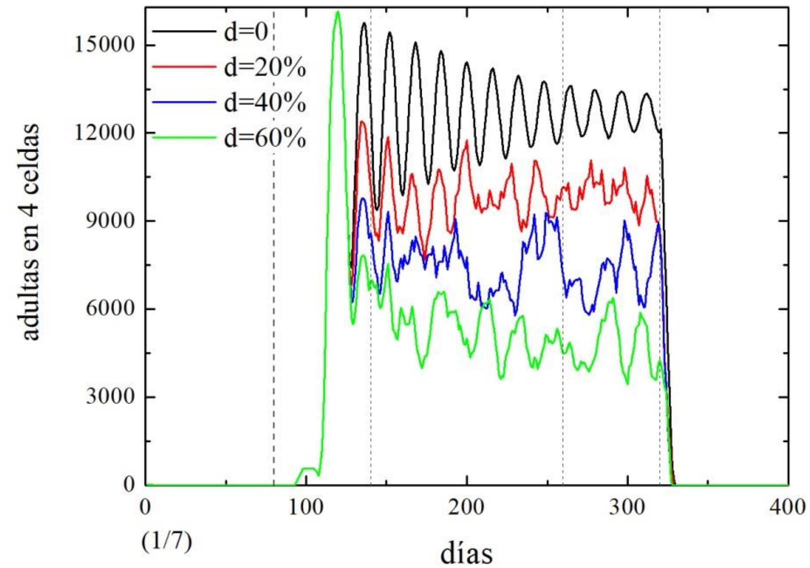


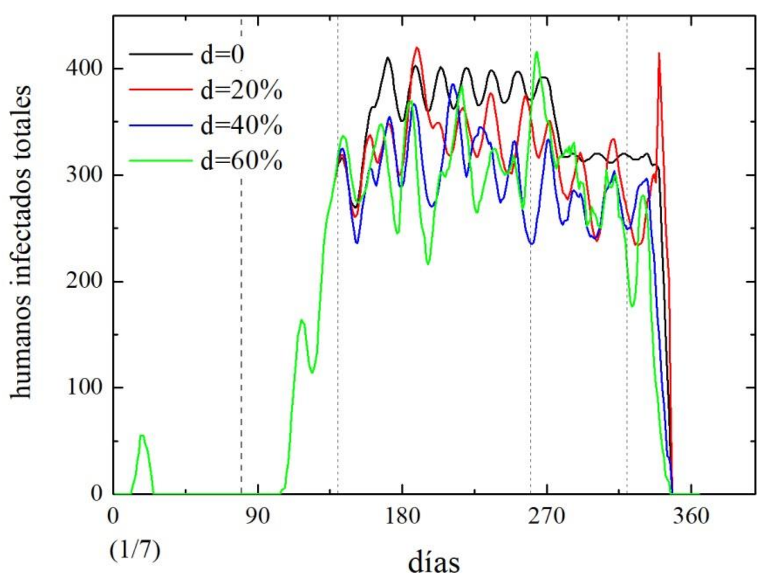


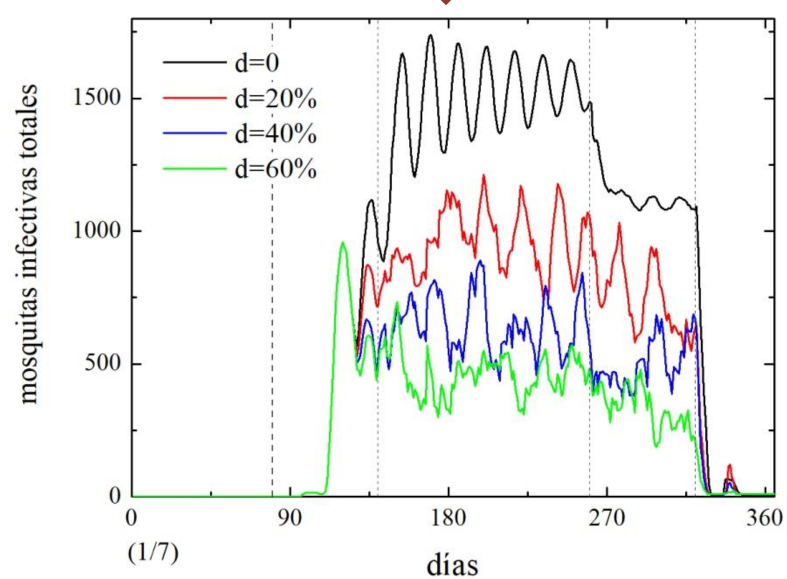


Conclusiones



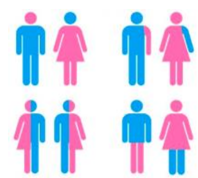




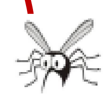


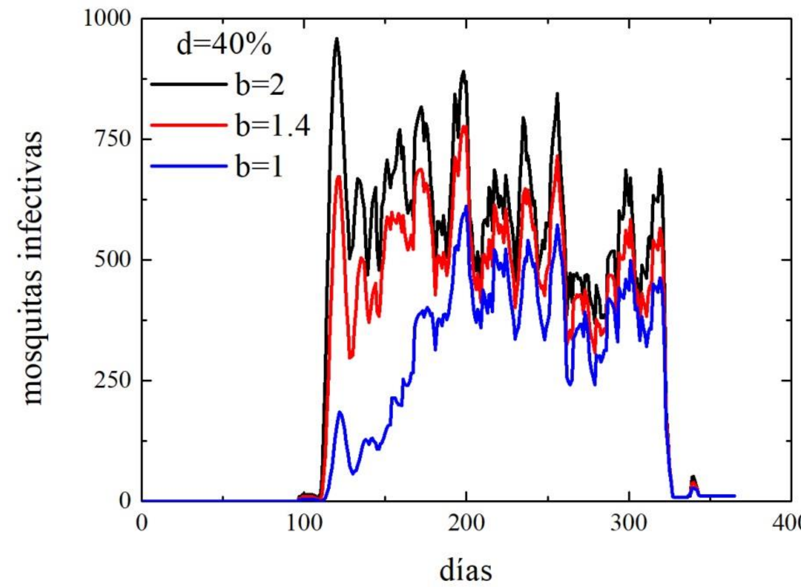
Conclusiones

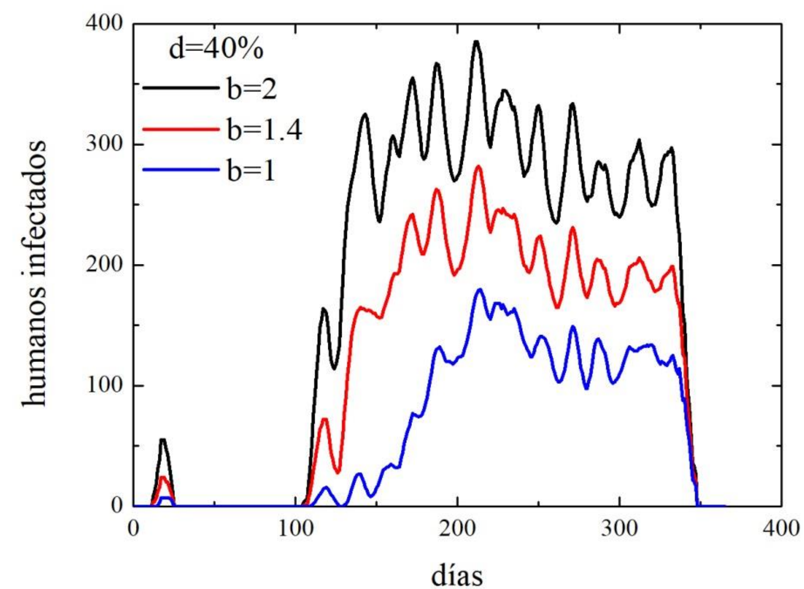
$P_{IM} = 1 - \exp(-b\ \beta_{MH}\ I_H / Po_H)$



$P_{IH} = 1 - \exp(-b\ \beta_{HM}\ I_M / Po_M)$







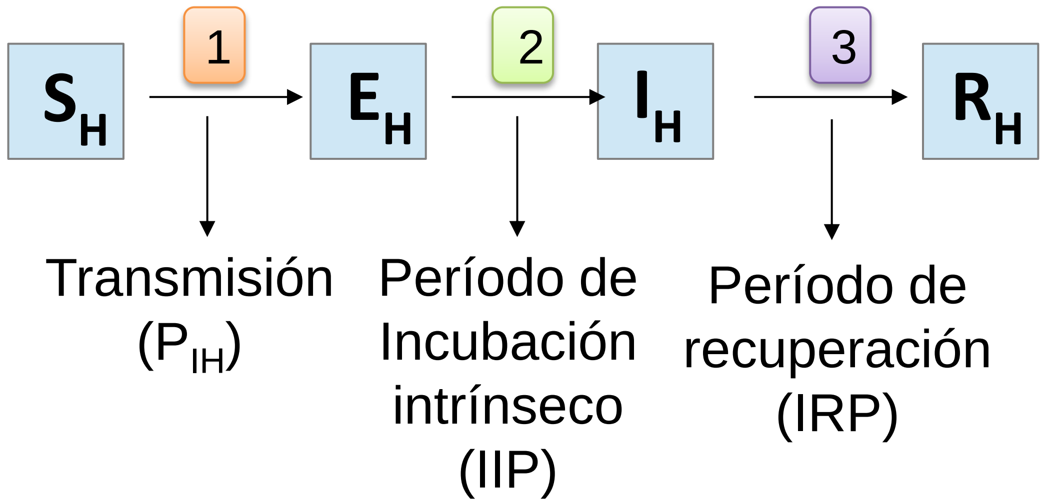
Futuros pasos

- **Influencia social en el SEIS**: aislamiento de S si hay I en el entorno, aislamiento de I si recibió información.
- **Acoplamiento** del modelo de mosquitas-agentes con el de humanos: ¿qué pasa si no hay humanos disponibles para todas las mosquitas?

¡Muchas gracias!

TREFEMAC 2019, 24 al 26 de abril, San Luis

Modelo epidemiológico para humanos



1) $$NS_H(t_{n+1}) = NS_H(t_n) - P_{IH}(t_n) * NS_H(t_n) + \mu_\beta * NS_H(t_n)$$

2) $$NE_H(t_{n+1}) = \sum_{t' = t - IIP}^{t' = IIP} NE_H(t')$$

IIP típico: 5 a **7** días

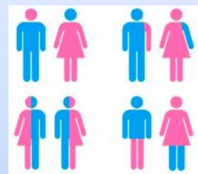
3) $$NI_H(t_{n+1}) = \sum_{t' = t - I^{RP}}^{t' = I^{RP}} NI_H(t')$$

IRP típico: 8 días

Modelo epidemiológico para las mosquitas

$S_M \rightarrow E_M \rightarrow I_M$

$P_{IM} = 1 - \exp(-b\, \beta_{MH}\, I_H / Po_H)$



P_{IM}= Prob. infecc. mosquitos

b= n° picaduras × día × mosq= 2

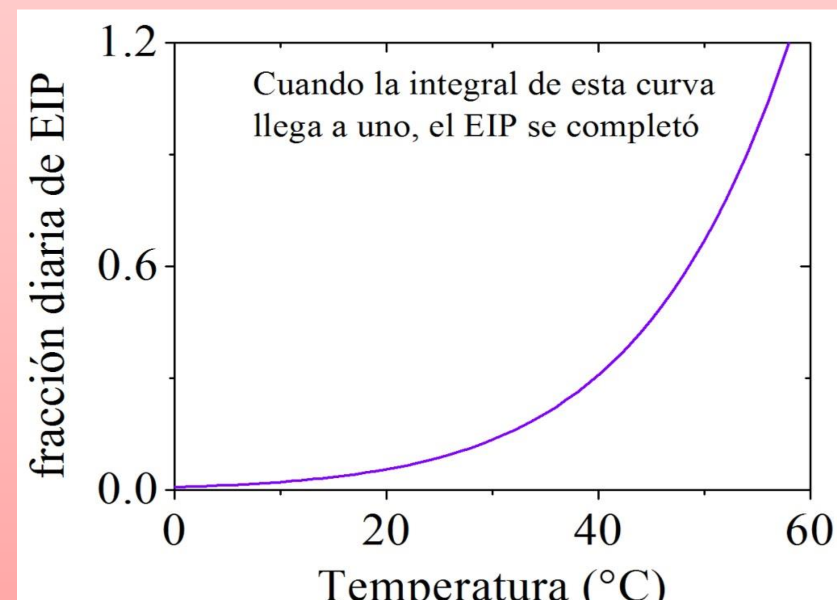
I_H = n° humanos × celda

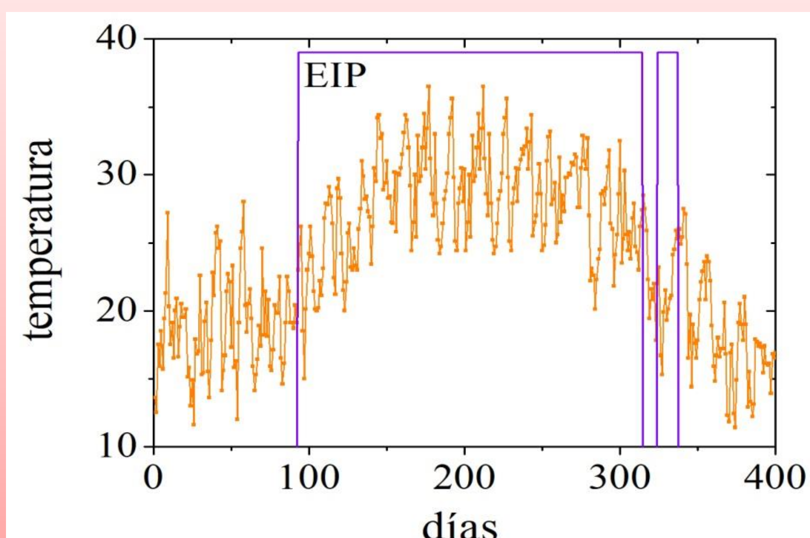
β_{MH}= prob. de infectarse × picar=0.17

Po_H = poblac. humanos total

Período de Incubación Intrínseco del virus en la mosquita (EIP)

El virus se incuba en la mosquita (7 a 21 días según T). Permanece infectiva el resto de su vida.





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Modeling dengue outbreaks

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ABSTRACT

We introduce a dengue model (SEIR) where the human individuals are treated on an individual basis (IBM) while the mosquito population, produced by an independent model, is treated by compartments (SEI). We study the spread of epidemics by the sole action of the mosquito. Exponential, deterministic and experimental distributions for the (human) exposed period are considered in two weather scenarios, one corresponding to temperate climate and the other to tropical climate. Virus circulation, final epidemic size and duration of outbreaks are considered showing that the results present little sensitivity to the statistics followed by the exposed period provided the median of the distributions are in coincidence. Only the time between an introduced (imported) case and the appearance of the first symptomatic secondary case is sensitive to this distribution. We finally show that the IBM model introduced is precisely a realization of a compartmental model, and that at least in this case, the choice between compartmental models or IBM is only a matter of convenience.

Bulletin of Mathematical Biology (2006) 68: 1945–1974
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ORIGINAL ARTICLE

A Stochastic Population Dynamics Model for *Aedes Aegypti*: Formulation and Application to a City with Temperate Climate

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Abstract *Aedes aegypti* is the main vector for dengue and urban yellow fever. It is extended around the world not only in the tropical regions but also beyond them, reaching temperate climates. Because of its importance as a vector of deadly diseases, the significance of its distribution in urban areas and the possibility of breeding in laboratory facilities, *Aedes aegypti* is one of the best-known mosquitoes. In this work the biology of *Aedes aegypti* is incorporated into the framework of a stochastic population dynamics model able to handle seasonal and total extinction as well as endemic situations. The model incorporates explicitly the dependence with temperature. The ecological parameters of the model are tuned to the present populations of *Aedes aegypti* in Buenos Aires city, which is at the border of the present day geographical distribution in South America. Temperature thresholds for the mosquito survival are computed as a function of average yearly temperature and seasonal variation as well as breeding site availability. The stochastic analysis suggests that the southern limit of *Aedes aegypti* distribution in South America is close to the 15°C average yearly isotherm, which accounts for the historical and current distribution better than the traditional criterion of the winter (July) 10°C isotherm.

Keywords Mathematical ecology · Population dynamics · *Aedes aegypti* · Stochastic model · Temperate climate

1. Introduction

Aedes aegypti is mostly a domestic mosquito and the primary vector for urban yellow fever and dengue. It is the most important vector for dengue in the Americas,

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E-mail address: solari@df.uba.ar (Hernán G. Solari).

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Modeling the complex hatching and development of *Aedes aegypti* in temperate climates

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Rain
Temperature
Local strains

ABSTRACT

Here, we present and discuss a compartmental stochastic model for *Aedes aegypti* conceived as a mathematical structure able to interpolate and extrapolate (predict) biological phenomena, and direct the attention to biological matters that need experimental elucidation. The model incorporates weather information in the form of daily temperatures and rain and pays particular attention to determining factors in temperate climates. Sufficiently large rains trigger egg hatching, which in turn leads to peaks in larval densities. Hatching is inhibited by the absence of bacteria (Gillett effect), a mechanism of relevance during the winter season and in seasons with isolated rains. The model also incorporates egg hatching independent of rains. Both egg hatching and larval development depend on the availability of food, which is modeled as bacteria produced at rates that depend on the temperature. Larval mortality and pupation rates depend on the larvae to bacteria ratio. The results of the model for egg laying activity were compared with field records during a normal season and a drought. Both the model and the records indicate that the egg laying activity of *Ae. aegypti* is not zero during the drought and recovers quickly when normal weather is reestablished. We studied the sensitivity of the model to different sets of physiological parameters published for a few different local populations of this species, and found that there is an important sensitivity to local characteristics that will affect some predictions of the model. We emphasize that if the information is going to be used to evaluate control methods, the life cycle of the mosquito must be studied for the local strain under the local environmental conditions (including food). We showed that the adult populations produced by the model are insensitive to certain combinations of parameters and that this insensitivity is related to the variability reported for different strains obtained from closely located places. When the model is considered in a larger biological context, it indicates that some standard procedures performed to measure the life cycle of *Ae. aegypti* in the laboratory might have a determining influence in the results.

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A model for the development of *Aedes* (*Stegomyia*) *aegypti* as a function of the available food

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HIGHLIGHTS

- Food in environment determines body size & time-statistics of adult emergence.
- Delay in pupation and dispersion of the cohort are captured by a single model.
- Larvae development sometimes waits to produce energy reserves before continuing.

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ABSTRACT

We discuss the preimaginal development of the mosquito *Aedes aegypti* from the point of view of the statistics of developmental times and the final body-size of the pupae and adults. We begin the discussion studying existing models in relation to published data for the mosquito. The data suggest a developmental process that is described by exponentially distributed random times. The existing data show as well that the idea of cohorts emerging synchronously is verified only in optimal situations created at the laboratory but it is not verified in field experiments. We propose a model in which immature individuals progress in successive stages, all of them with exponentially distributed times, according to two different rates (one food-dependent and the other food-independent). This phenomenological model, coupled with a general model for growing, can explain the existing observations and new results produced in this work. The emerging picture is that the development of the larvae proceeds through a sequence of steps. Some of the steps depend on the available food. While food is in abundance, all steps can be thought as having equal duration, but when food is scarce, those steps that depend on food take considerably longer times. For insufficient levels of food, increase in larval mortality sets in. As a consequence of the smaller rates, the average pupation time increases and the cohort disperses in time. Dispersion, as measured by standard deviation, becomes a quadratic function of the average time indicating that cohort dispersion responds to the same causes than delays in pupation and adult emergence. During the whole developmental process the larva grows monotonically, initially at an exponential rate but later at decreasing rates, approaching a final body-size. Growth is stopped by maturation when it is already slow. As a consequence of this process, there is a slight bias favoring small individuals: Small individuals are born before larger individuals, although the tendency is very weak.