
BRA
30754
Foto : Fred Hoffmann

Stage-Structured Model for *Aedes Aegypti* and *Wolbachia* Interaction

HELIO SCHECHTMAN [1] Daniel Villela [1] Max O Souza [2]

[1]Programa de Computação Científica, Fundação Oswaldo Cruz, Rio de Janeiro, Brazil

[2]Departamento de Matemática Aplicada, Universidade Federal Fluminense, Niterói, RJ, Brazil

June 2015

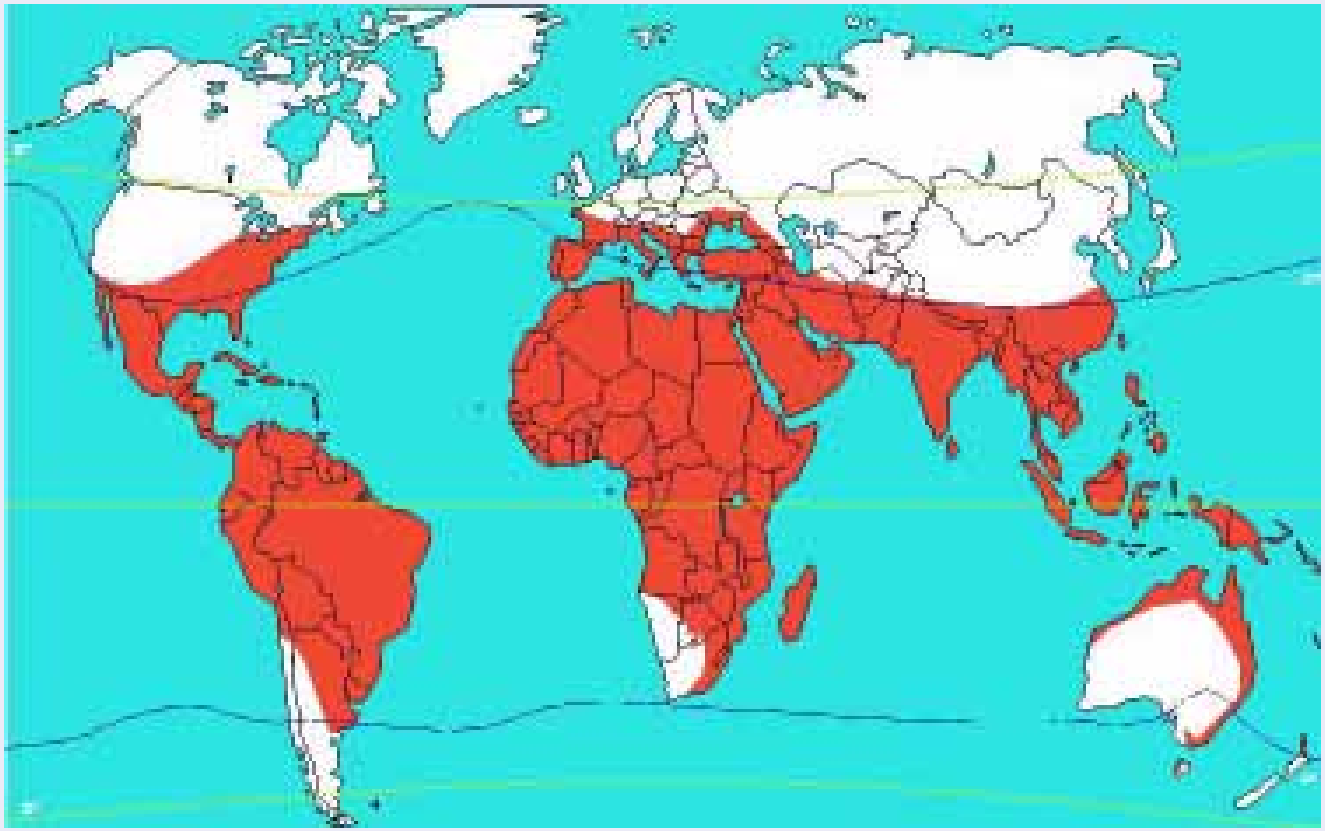
THE MOSQUITO

Aedes (*Stegomyia*) *aegypti* (Diptera: Culicidae) (Linnaeus)

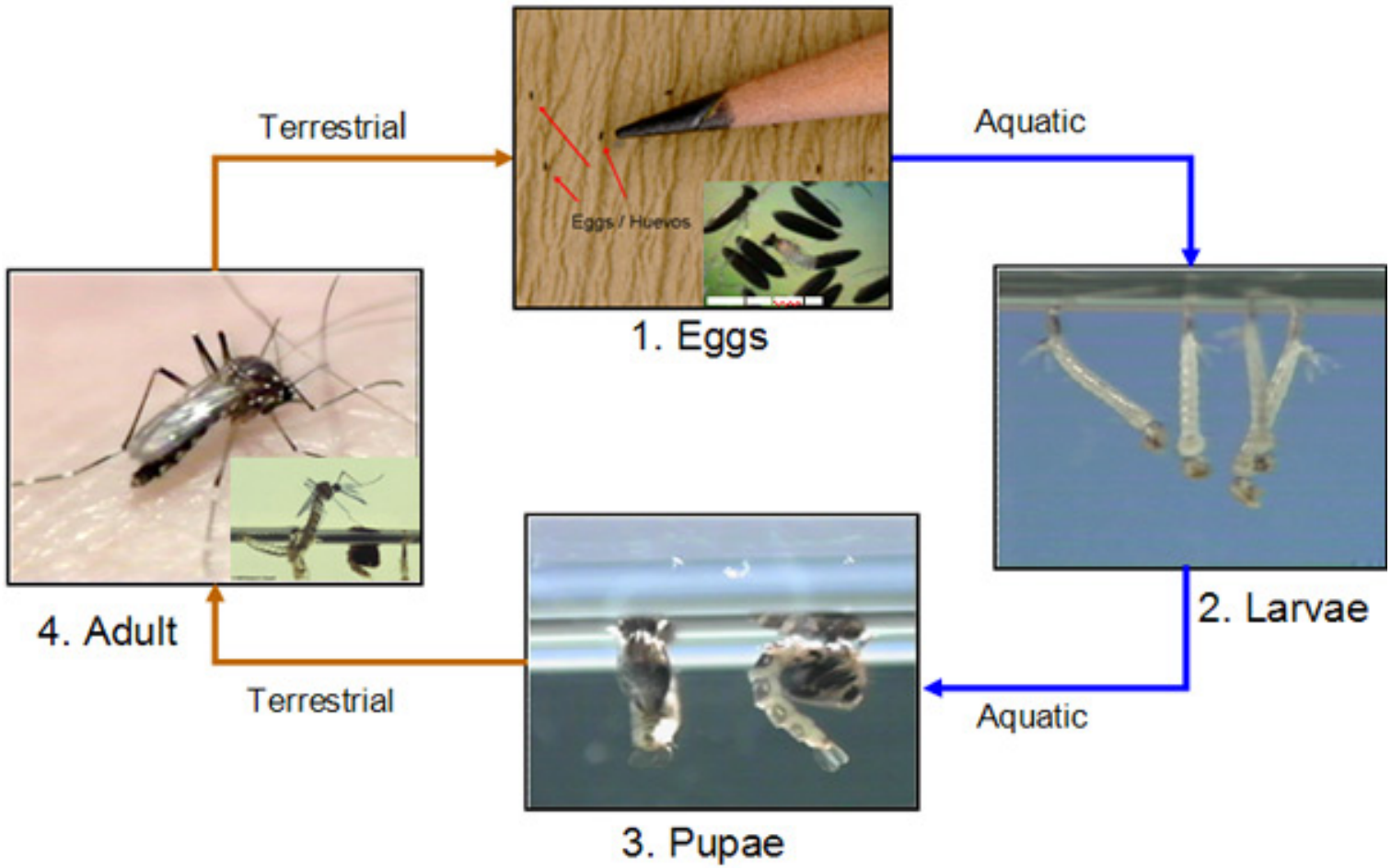
Tropical Areas
Sub-Tropical Areas
Worldwide

GEOGRAPHICAL DISTRIBUTION

Mosquito



MOSQUITO BIOLOGY



PUBLIC HEALTH ISSUE

Aedes aegypti is a vector for:

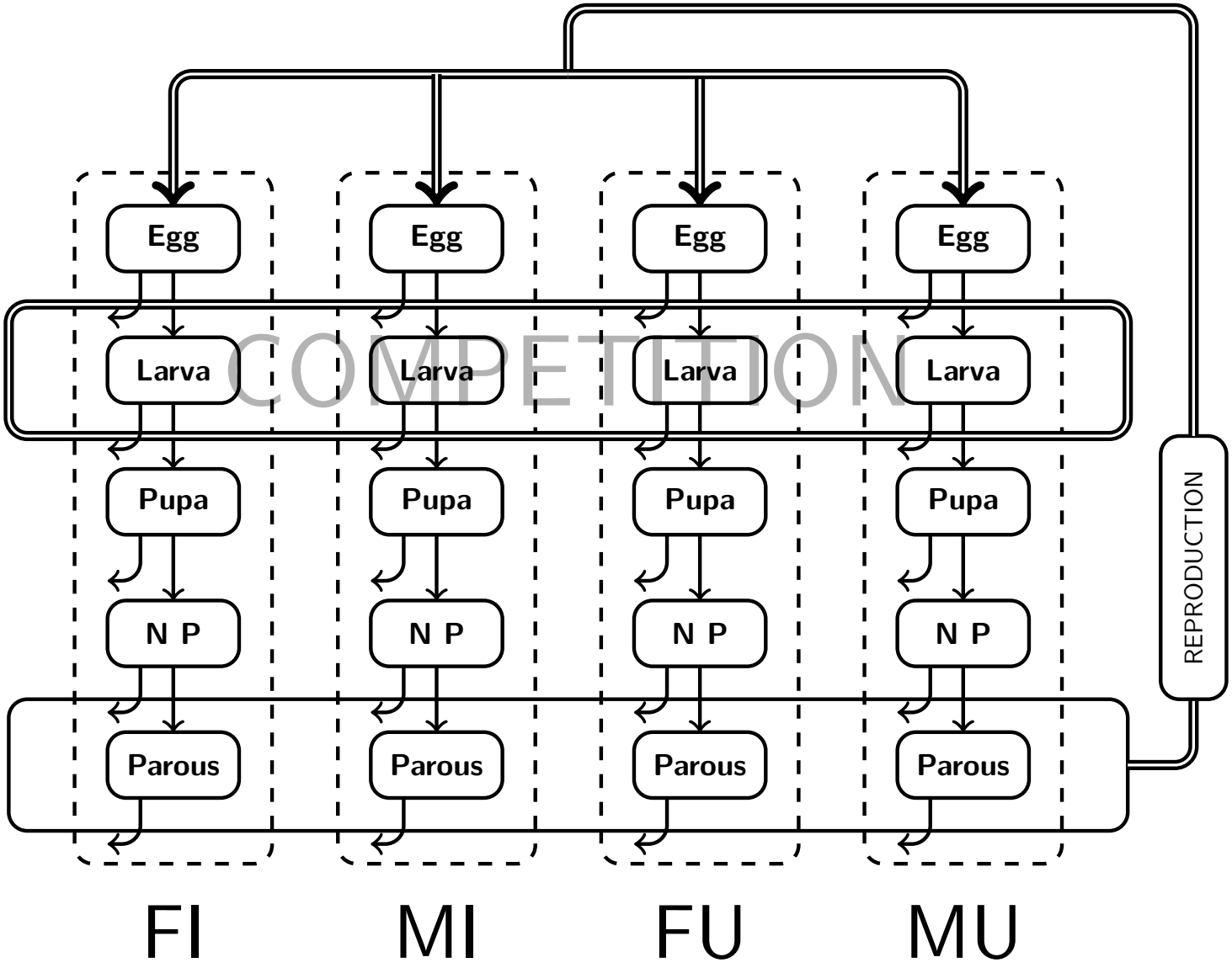
- Dengue
- Yellow Fever
- Chikungunya
- Etc.

DENGUE ELIMINATION

Prophylaxis

- **No** vaccine
- **Mosquito population control**
- *Wolbachia*-infected mosquitoes

POPULATION DYNAMICS MODEL



SYSTEM ODE

$$\begin{cases} \dot{Y}_{1,j} &= B(j, Y_{5,.}) - \left(\tau_1^j(t) + d_1^j\right) Y_{1,j} \\ \dot{Y}_{2,j} &= \tau_1^j(t) Y_{1,j} - \left(\tau_2^j(t) + d_2^j + s^j \sum_{l=1}^{4} Y_{2,l}\right) Y_{2,j} \\ \dot{Y}_{3,j} &= \tau_2^j(t) Y_{2,j} - \left(\tau_3^j(t) + d_3^j\right) Y_{3,j} \\ \dot{Y}_{4,j} &= \tau_3^j(t) Y_{3,j} - \left(\tau_4^j + d_4^j\right) Y_{4,j} \\ \dot{Y}_{5,j} &= \tau_4^j Y_{4,j} - d_5^j Y_{5,j} \end{cases}$$

where t is measured in days, and $Y_{i,j}$ denotes stage i within infected/uninfected female/male $j = 1, 2, 3, 4$. For instances, parous infected female $Y_{5,1}$ and parous uninfected male $Y_{5,4}$.

BIRTH FUNCTION

$$B(j, Y_{5,.}) = Y_{5,1}\left(\frac{Y_{5,2}}{\sum_{k=1}^{2} Y_{5,2k}}\right)(SR_{1,j})(br_1)(1-cbr_1)(VT_{1,j})(1-ci_1)$$
$$+ Y_{5,1}\left(\frac{Y_{5,4}}{\sum_{k=1}^{2} Y_{5,2k}}\right)(SR_{2,j})(br_2)(1-cbr_2)(VT_{2,j})(1-ci_2)$$
$$+ Y_{5,3}\left(\frac{Y_{5,2}}{\sum_{k=1}^{2} Y_{5,2k}}\right)(SR_{3,j})(br_3)(1-cbr_3)(VT_{3,j})(1-ci_3)$$
$$+ Y_{5,3}\left(\frac{Y_{5,4}}{\sum_{k=1}^{2} Y_{5,2k}}\right)(SR_{4,j})(br_4)(1-cbr_4)(VT_{4,j})(1-ci_4)$$

where
$(SR_n, j) = (sr_n, j)$ for $j = 1, 3$;
$(SR_n, j) = (1 - sr_n, j)$ for $j = 2, 4$.
$(VT_n, j) = (vt_n, j)$ for $j = 1, 2$;
$(VT_n, j) = (1 - vt_n, j)$ for $j = 3, 4$.
$br_n = 4$

ESTABLISHMENT OF BASIC INITIAL CONDITIONS

Assume the following non-infected population distribution:

Quantity	Value	Fraction of Total	Description
Y_1	39,160,000	0.979	Total number of eggs
Y_2	240,000	0.006	Total number of larvae
Y_3	40,000	0.001	Total number of pupae
Y_4	280,000	0.007	Total number of non-parous winged mosquitoes
Y_5	280,000	0.007	Total number of parous winged mosquitoes

Evolve non-infected population through $4,384$ **days or** 12 **years and** 1 **day.**

BASIC INITIAL CONDITION (BIC) POPULATION

Quantity	Value	Fraction of Total	Description
Y_1	106,380,800	0.9743	Total number of eggs
Y_2	949,598	0.0087	Total number of larvae
Y_3	155,330	0.0014	Total number of pupae
Y_4	423,110	0.0039	Total number of non-parous winged mosquitoes
Y_5	1,279,318	0.0117	Total number of parous winged mosquitoes

* assume sex-ratio of $1/2$

ESTABLISHMENT POPULATION THRESHOLD

1. Apply same sex-ratio to BIC for infected and uninfected mosquitoes

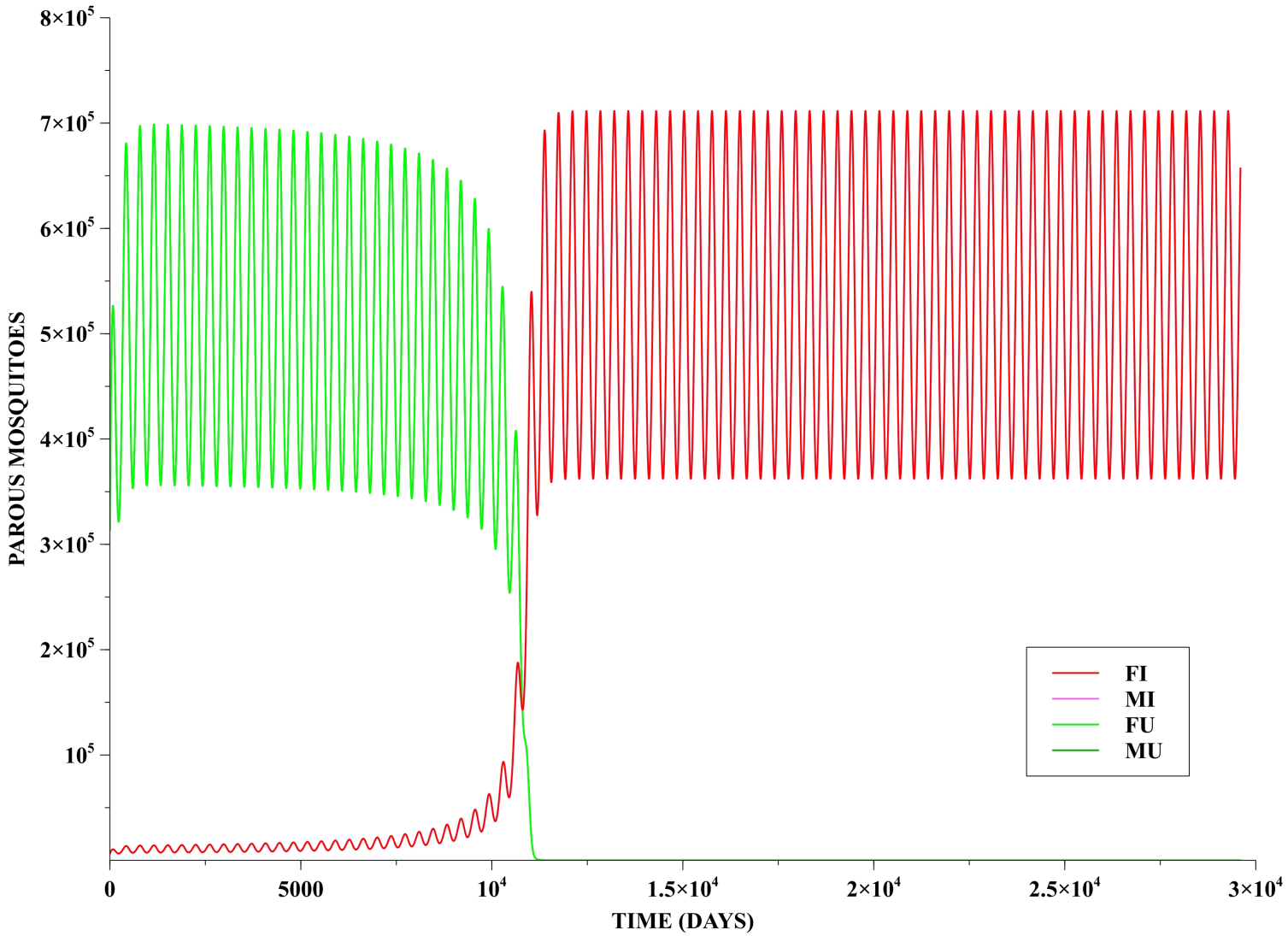
ESTABLISHMENT POPULATION THRESHOLD

1. Apply same sex-ratio to BIC for infected and uninfected mosquitoes
2. Apply same share proportion for all stages to infected and uninfected population, for instances 0.85 uninfected and 0.15 infected

ESTABLISHMENT POPULATION THRESHOLD

1. Apply same sex-ratio to BIC for infected and uninfected mosquitoes
2. Apply same share proportion for all stages to infected and uninfected population, for instances 0.85 uninfected and 0.15 infected
3. Verify if Wolbachia-infected mosquitoes prevail
4. If invaded, reduce share proportion of Wolbachia-infected
5. If not invaded, increase share proportion of Wolbachia-infected
6. REPEAT steps 3 to 5 until desired accuracy

TYPICAL RUN - POPULATION THRESHOLD



EXPERIMENTAL PROCEDURE - MOSQUITO RELEASE

1. Apply sex-ratio to BIC for purely uninfected mosquitoes population

EXPERIMENTAL PROCEDURE - MOSQUITO RELEASE

1. Apply sex-ratio to BIC for purely uninfected mosquitoes population
2. Release infected mosquitoes at desired stage and proportion at specified frequency, for instances 0.15 of Parous BIC population at weekly intervals for one year for a given density dependent death

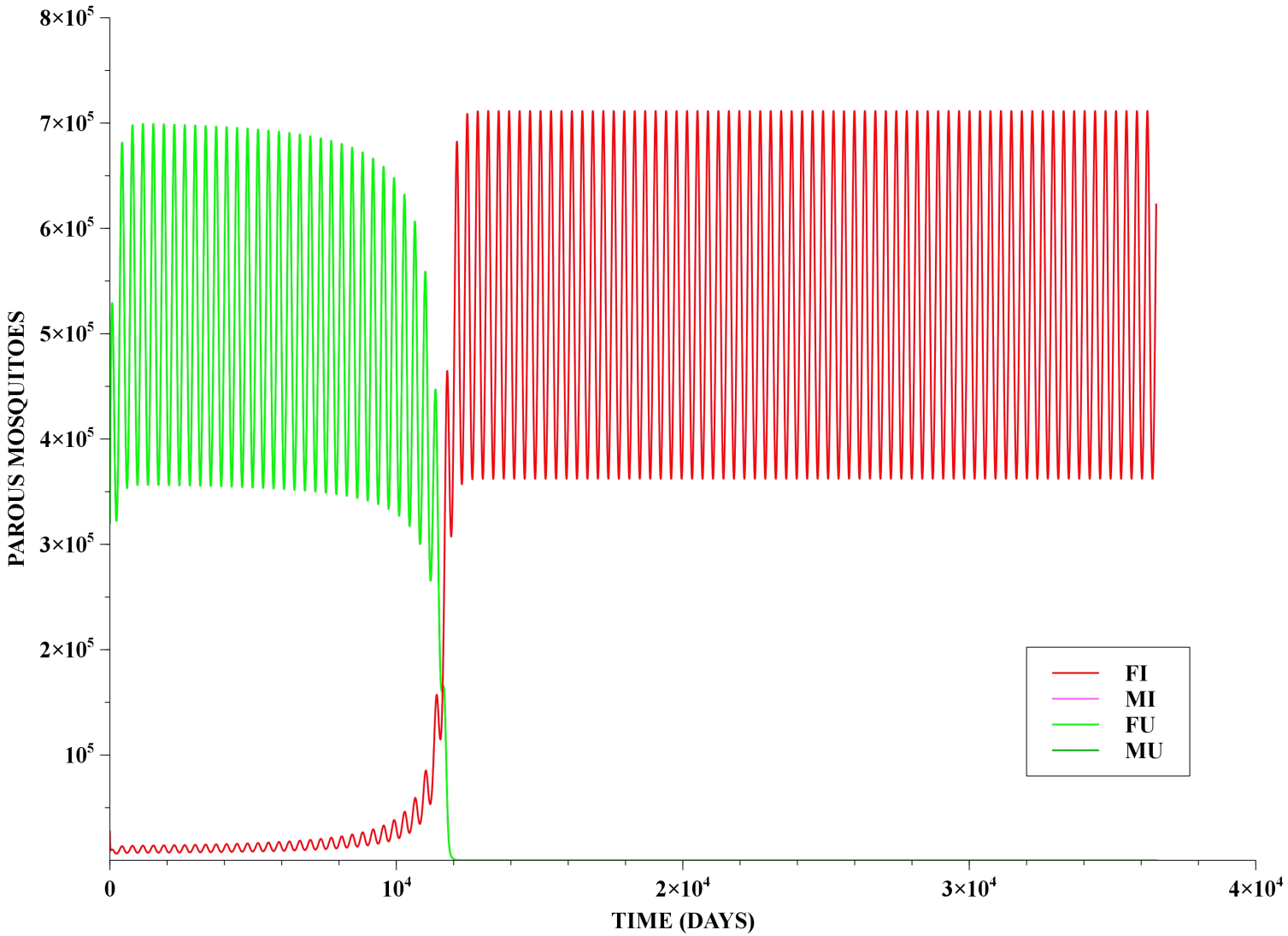
EXPERIMENTAL PROCEDURE - MOSQUITO RELEASE

1. Apply sex-ratio to BIC for purely uninfected mosquitoes population
2. Release infected mosquitoes at desired stage and proportion at specified frequency, for instances 0.15 of Parous BIC population at weekly intervals for one year for a given density dependent death
3. Verify if Wolbachia-infected mosquitoes prevail
4. If invaded, reduce share proportion of Wolbachia-infected
5. If not invaded, increase share proportion of Wolbachia-infected
6. REPEAT steps 3 to 5 until desired accuracy

MOSQUITO RELEASES

- 3 stages:
  Eggs; or
  Larvae; or
  Parous winged mosquitoes
- Periodicity
  Single release at 1st January; or
  52 weekly releases for a year

TYPICAL RUN - MOSQUITO RELEASE



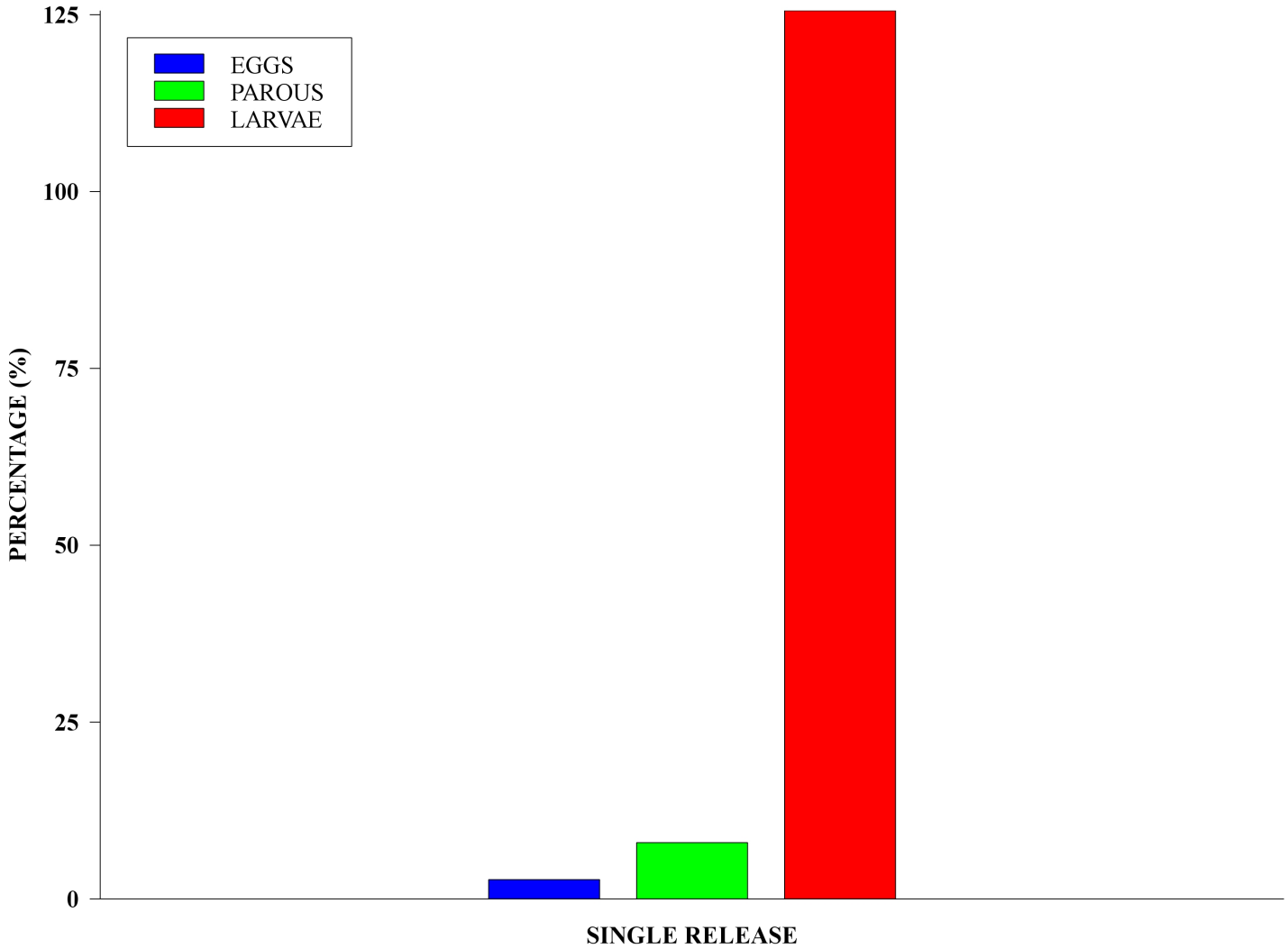
RESULTS

POPULATION THRESHOLD

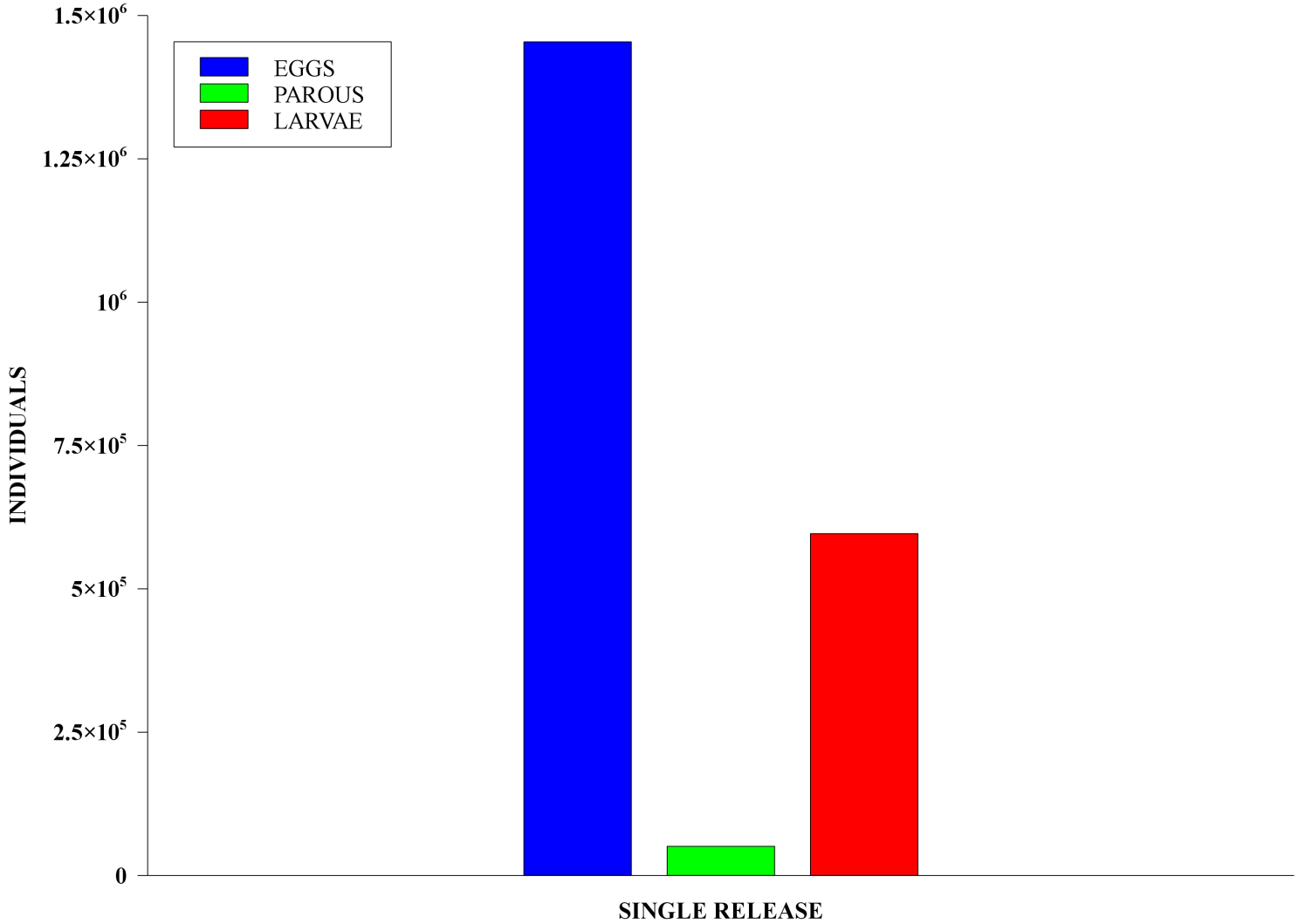
- $0.0089416505 \approx 1\%$ FI
- $0.0089416505 \approx 1\%$ MI

- $0.49105835 \approx 49\%$ FU
- $0.49105835 \approx 49\%$ MU

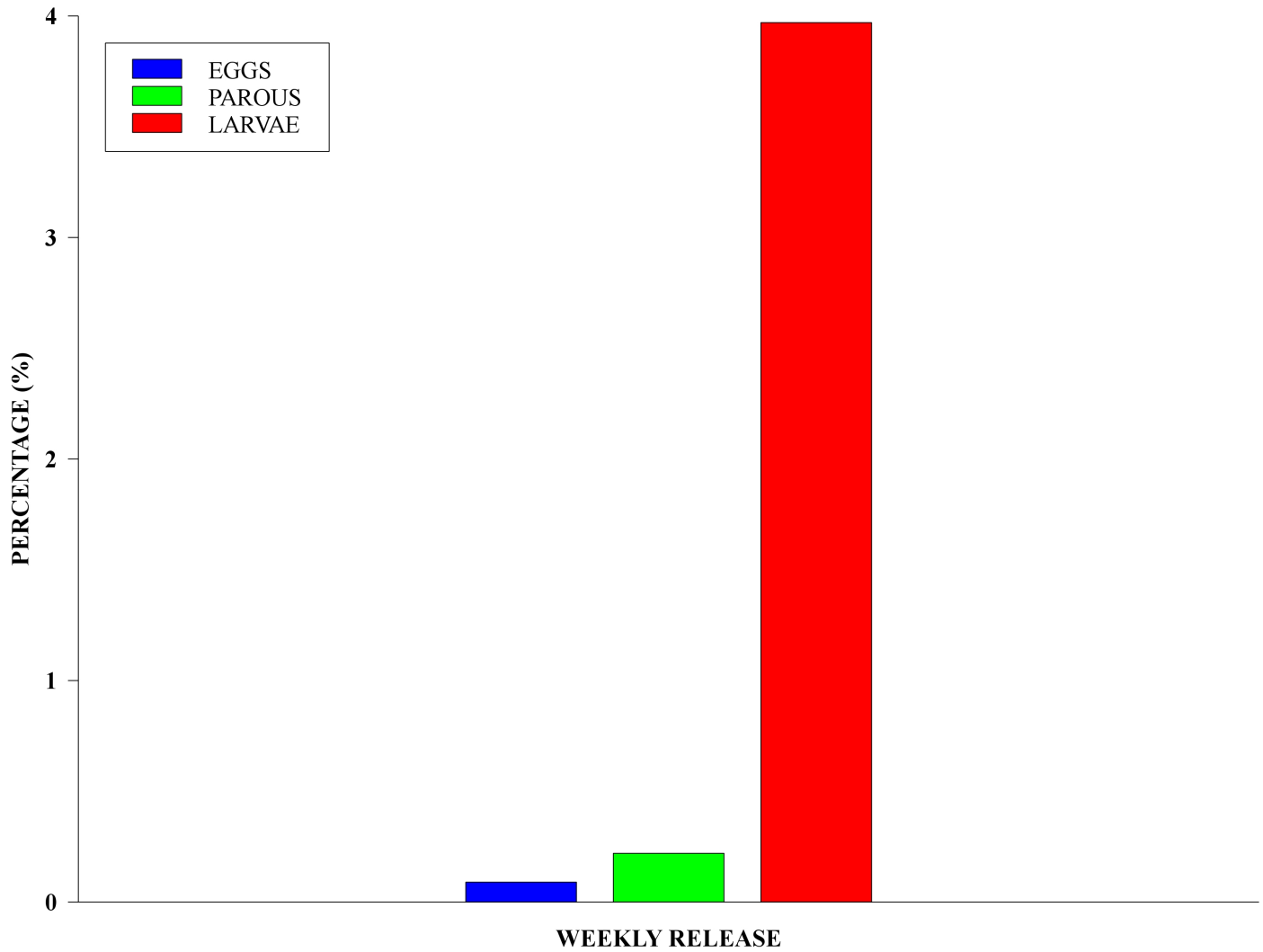
SINGLE RELEASE - PERCENTAGE



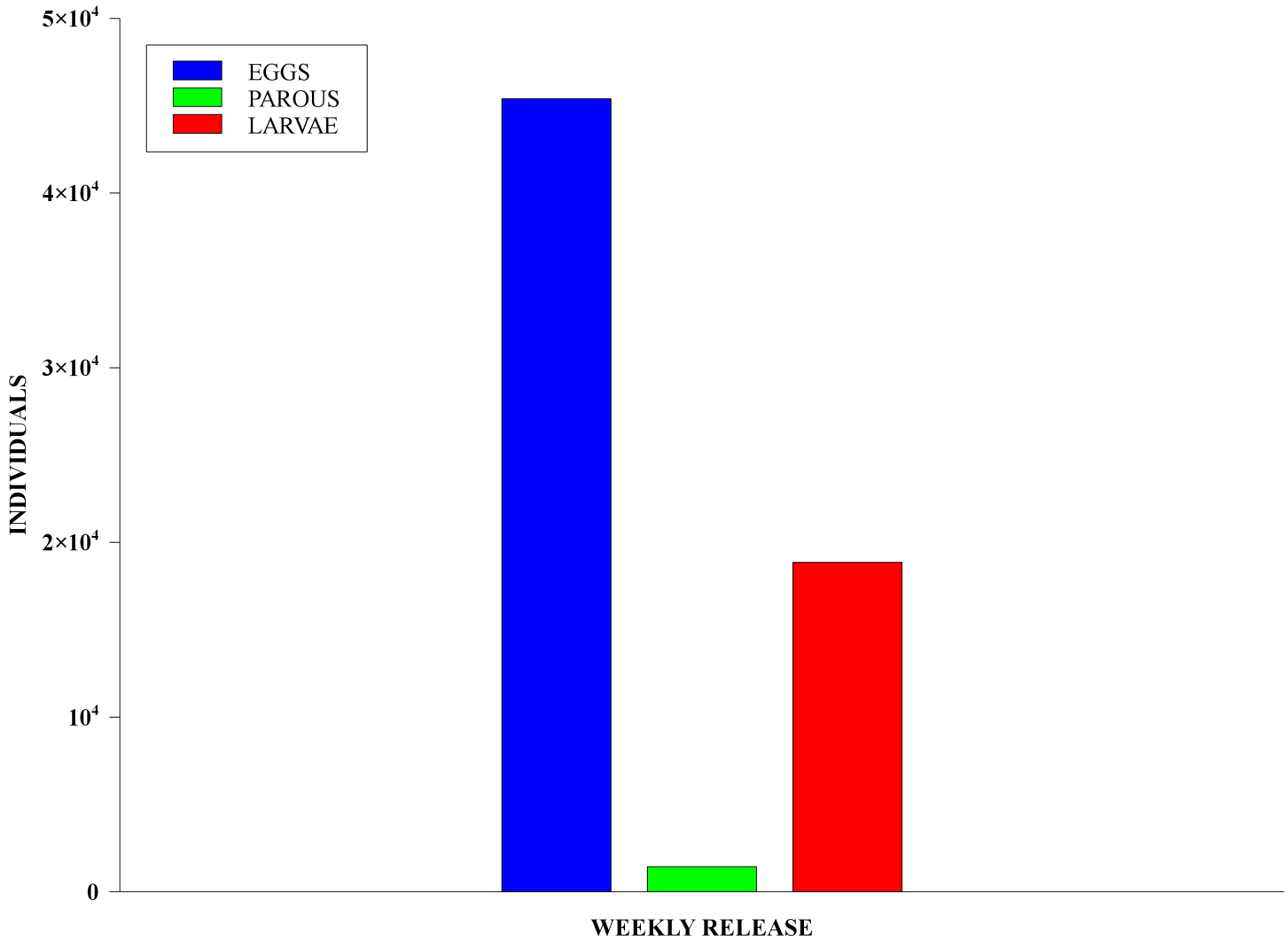
SINGLE RELEASE - ABSOLUTE NUMBERS



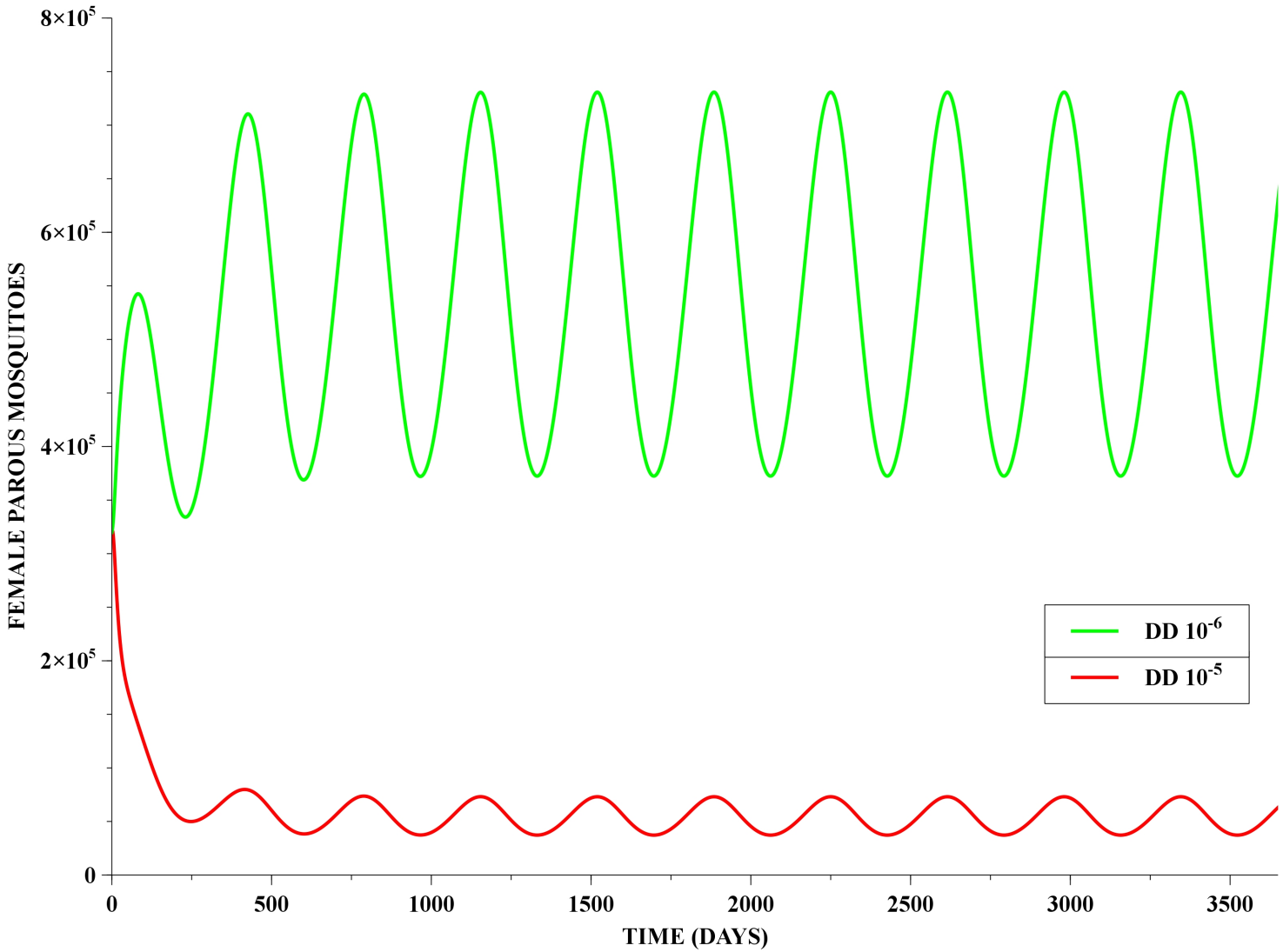
WEEKLY RELEASE - PERCENTAGE



WEEKLY RELEASE - ABSOLUTE NUMBERS



DENSITY DEPENDENT DEATH EFFECTS



DISCUSSION - Density Dependent Death

- SCALING parameter for Total Population and Release
- Fast effect

DISCUSSION - Minimum Percentage for Invasion

- for SINGLE Release
  3 % of EGGS sub-population
  8 % of PAROUS sub-population
  126 % of LARVAE sub-population

DISCUSSION - Minimum Percentage for Invasion

- for WEEKLY Releases
  0.1 % of EGGS sub-population
  0.2 % of PAROUS sub-population
  4 % of LARVAE sub-population

DISCUSSION - Practical Implementation

- Different difficulties for each stage
- POPULATION SIZE UNKNOWN
- FIOCRUZ can produce 30,000 parous mosquitoes per week
- for SINGLE Release
  50,930 individuals of PAROUS sub-population
- for WEEKLY Releases
  454 individuals of PAROUS sub-population

DISCUSSION - in summary

- Invasion is possible
- Feasible with existent means
- Different "efforts"

Thank You!!!!


How's your first flight son?
Feels great, Dad! Everyone was clapping for me!