Modeling a vaccination campaign against monkeypox in Mexico City

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## Introduction

Since May 2022 the global outbreak of Monkeypox (MPX) has been reported in over 118 countries with most cases occurring among Men who have Sex with Men (MSM) (1–4). In Mexico, 98% of cases have been reported in men, most of these are aged 20-50 (5). To date 2,654 cases have been confirmed with most of them (60%) being reported in Mexico City, where the only laboratory in the country capable of testing for MPX (before October 6th) is headquartered (6). As the case count continues rising, activists have demanded more testing and access to vaccines. To date the country has not implemented a vaccination campaign.

The purpose of this document is to model the prevention opportunity of a vaccination campaign against MPX in Mexico City.

## Methods

### Data

#### Monkeypox cases

Weekly incident cases were obtained from the reports of the General Directorate of Epidemiology of Mexico (5).

#### Parameter information

### Mathematical model

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| Figure 1: Diagram of the transmission mechanics of the model. There are five different categories of individuals: Susceptible , Exposed , Infected , Recovered , and Vaccinated . We assume vaccinated and recovered individuals become immune for the remaining of the modeled period. |

Our model is a pair-formation Susceptible-Exposed-Infected-Recovered (SEIR) system of differential equations adapted from (7). Briefly, in pair formation models the infection is driven by the rate of sexual **partnership** formation between individuals and transmission probabilities per sexual encounter within the partnership (2,8,9). In these models, **single** individuals (individuals that don’t form partnerships) don’t get infected nor infect others. A sexual partnership starts when two individuals have their first sexual encounter (rate of partnership formation) and will continue having sexual encounters (at a rate ) until the partnership ends (rate of partnership dissolution). After a partnership dissolves, individuals become single again.

The disease is transmitted when two individuals have a sexual encounter with one of them being susceptible and the other being infected . Once contagion takes place the susceptible individual becomes exposed (incubating) . An exposed individual eventually evolves to an infectious individual at a rate . Infectious individuals recover at a rate . Recovered individuals are represented by the letter . Susceptible individuals can also become vaccinated at a rate . We assume that vaccinated and recovered individuals cannot be reinfected.

The differential equations representation for the model and the compartmental diagram can be found in [Appendix 6](#sec-diffeq).

#### Model Fitting

We used the weekly incident cases of (5) for Mexico City for each week and fitted them against the modeled incident cases for the same week. We assumed that only a fraction of all the cases corresponded to the observed cases, . And that the observed cases follow a Negative Binomial distribution parametrized by its mean and precision :

with

[Table 2](#tbl-parameters) contains information regarding the priors for all parameters. Trajectories for the model were simulated via the DifferentialEquations package using the Rodas4 algorithm (10). Parameter fitting was done via No-U-Turn-Sampling (NUTS) with the Turing library in Julia version 1.8.2 (11–13). We used the and Gelman-Rubin’s test to assess convergence (14). All graphics were done in R version 4.2.1 (2022-06-23) using ggplot2 (15,16).

#### Estimation of the basic reproductive number,

TBD

#### Scenario simulation

We used the simulated posterior distribution of the model’s parameters to construct the baseline scenario with no vaccination . We then repeated the simulations under different vaccination rate scenarios .

### Code and data availability

Both the code for the model and the data can be found in our [Github repository](https://github.com/RodrigoZepeda/mpx)

## Results

By October 28 2022 a total of 1601 cases have been reported for Mexico City.

## References

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## Model

The compartmental diagram of the model is the following:

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| --- |
| Figure 2: Diagram of the model. Bright red node is the main driver of the infection as it represents a partnership between a Susceptible and an Infected individual. This partnership irradiates the infection towards if the susceptible becomes infected and the partnership continues. The partnership might also dissolve into the susceptible and the infected or might not result in an infection but a recovery of the infected partner . |

Where the variables are specified in [Table 1](#tbl-variables).

Table 1: Variables used in the model [Equation 1](#eq-model).

| Variable | Definition |
| --- | --- |
|  | **Single** susceptible individuals |
|  | **Single** exposed individuals |
|  | **Single** infected individuals |
|  | **Single** recovered individuals |
|  | **Single** vaccinated individuals |
|  | **Partnership** of two individuals in which one partner belongs to category and the other to category (*e.g.* represents a partnership between a susceptible and an infected individual). |
|  | **Overall** cummulative infective cases. Total numner of infective cases independent of partnership status over all of the pandemic |
|  | **Overall** total infective cases. Total number of infective cases at a moment in time. Independent of partnership status. |
|  | **Overall** incident cases. New cases independent of partnership status. |

The differential equation representation is given by:

where represents the total number of individuals (MSM) in the population. Initial conditions for the model are given by:

with . The rest of the initial values are equal to zero.

The parameters and their definitions are established in [Table 2](#tbl-parameters).

Table 2: Parameters used in the model [Equation 1](#eq-model).

| Parameter | Definition |
| --- | --- |
|  | Partnership formation rate. |
|  | Partnership dissolution rate. |
|  | Vaccination rate. |
|  | Incubation rate. |
|  | Infection recovery rate. |
|  | Probability of transmission per contact. |
|  | Contact rate per partnership. |
|  | Precision of the observed incidence cases. |
|  | Probability of being a detected case. |
|  | The total of MSM in Mexico City |
|  | The proportion of **single** susceptible cases at the beginning of the epidemic. |
|  | The proportion of **single** infected cases at the beginning of the epidemic. |

The total number of infected individuals at any time can be estimated as:

and the cumulative number of infected individuals (cumulative cases) is given by the solution to the differential equation:

The number of incident cases at week , is given by the difference in cumulative cases [Equation 3](#eq-cumcases):

## Parameter distributions