

Modelling a bubonic plague outbreak in a population of prairie dogs.

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A short introduction to PEPA

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A PEPA model is represented as:

- the composition of components which undertake actions $(\alpha, r).P$
- a system equation which defines the initial state and the action that require cooperation between two or more components.

Motivation

The motivations behind this model are:

- Answer the question: to what extent can PEPA model epidemiological problems?
- Find out which issues arise.
- Try to find satisfactory solutions to those issues.

Some useful preliminary facts

The bubonic plague in a few facts:

- It is an infection of the lymphatic system, and the main source of transmission are fleas.
- It is estimated to have killed about 200 million people.
- It kills about 50% of patients in 3 to 7 days without treatment.

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Prairie dogs:

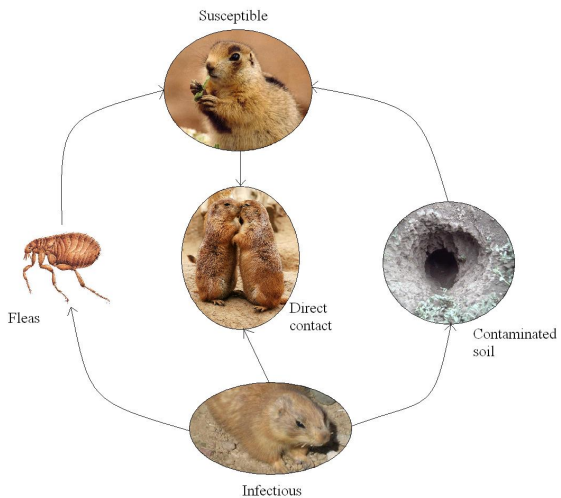
- are rodents living in the grasslands in North America.
- are a type of ground squirrels.
- are highly social animals. They live in large colonies which are composed of families of 1 male and 2 to 4 females.

Presentation

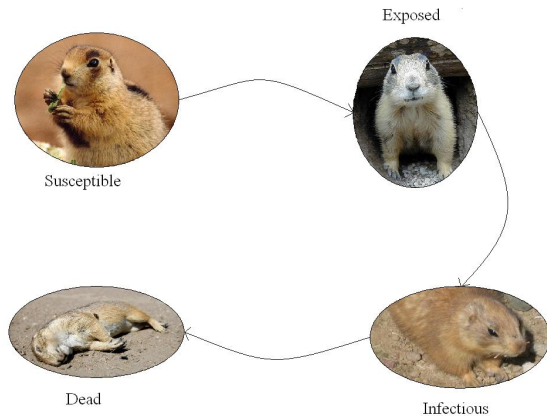
The bubonic plague in prairie dogs:

- It was introduced to the United States at the beginning of the 20th century and spread to western and central parts of the country by the 1940s.
- Prairie dogs are highly susceptible to the bubonic plague, and the mortality of infecteds is almost 100%.
- The plague combined with the prairie dogs' bad reputation have resulted in a huge decrease in the prairie dog population.

Behaviour of the disease 1



Behaviour of the disease 2



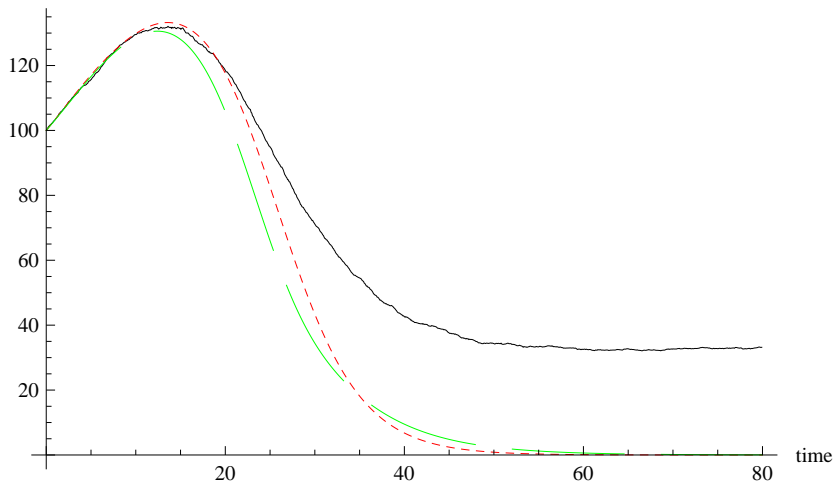
What are we modelling here?

The model consists of:

- A single burrow, with 100 prairie dogs and 1000 fleas.
- Initially, 2 prairie dogs and 10 fleas are infected.
- The parameters used are taken from a paper from Webb et al.

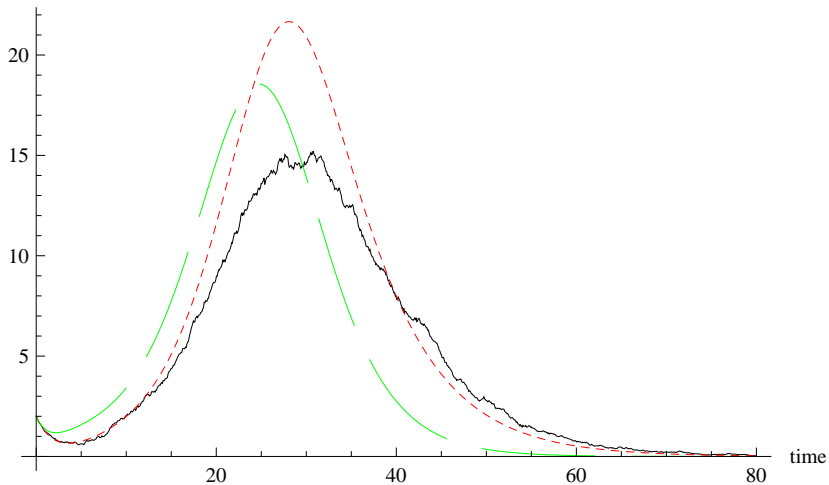
Graph

Population

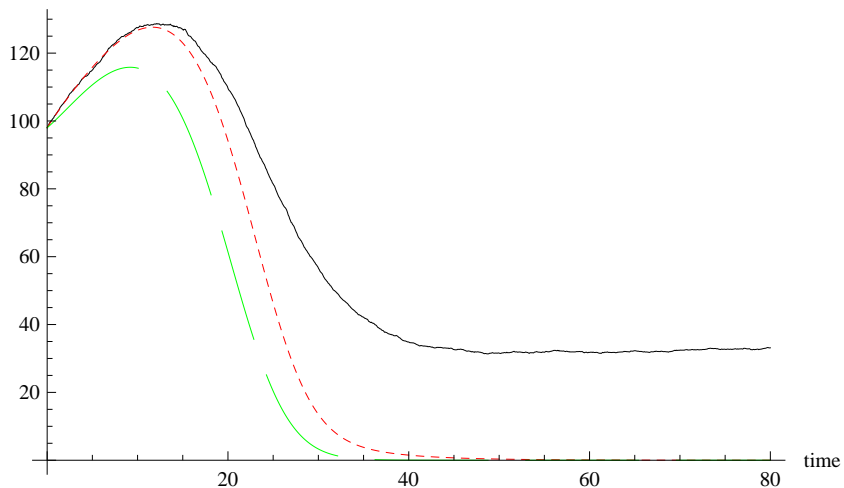


Simulations: Infectious

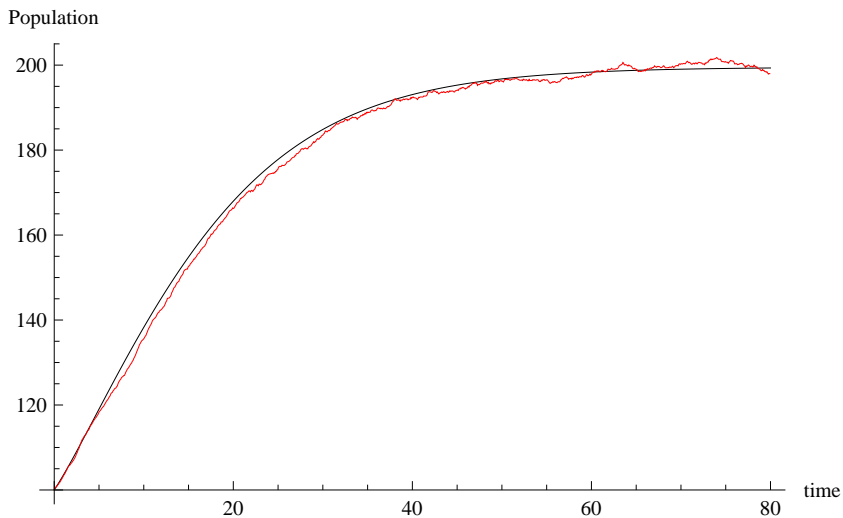
Infectious



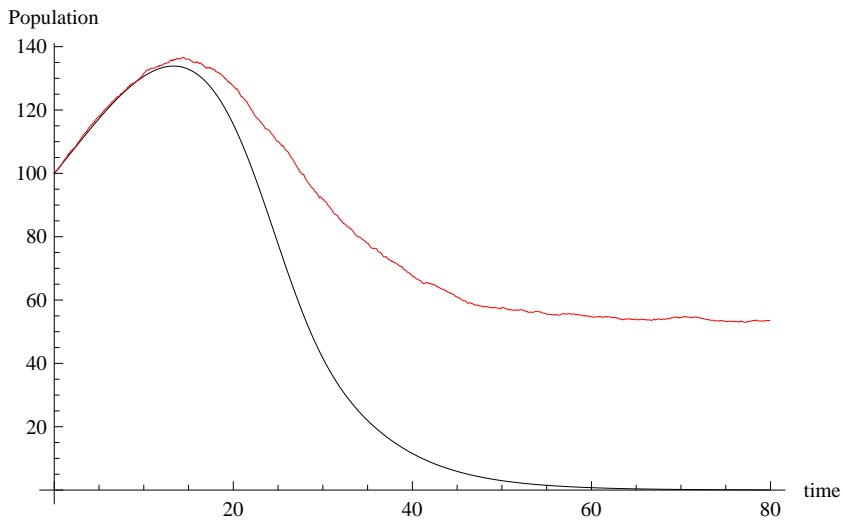
Simulations: susceptibles



Influence of the vectors: fleas and direct transmission



Influence of the vectors: indirect transmission



Sensitivity analysis

Parameter value	Time at which the town is empty	Percentage of outbreaks
$contact_env_rate \times 2$	25	78%
$contact_env_rate$	35	84%
$contact_env_rate/2$	50	83%
$contact_env_rate/4$	90	80%
$contact_env_rate/8$	180	NA

Conclusion

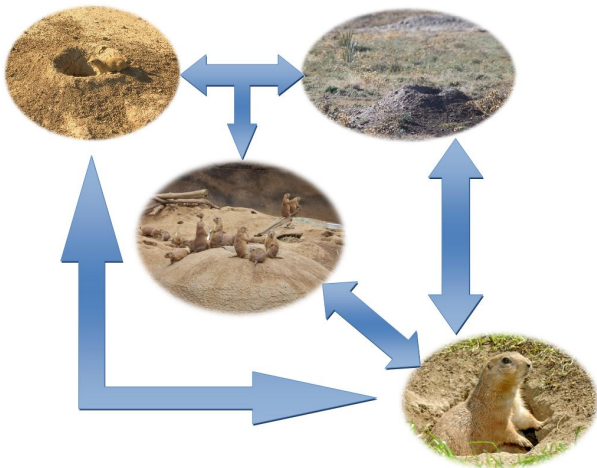
- The ODEs derived from the model give similar results to what is found in the literature.
- Simulations show that ODEs might be neglecting the situation where the disease dies out immediately.
- The sensitivity analysis confirmed that the model is not very sensitive to the indirect transmission parameter.
- However, this model is not sufficient to understand the whole mechanism of the disease. We need to add space.

What are we modelling this time?

The model consists of:

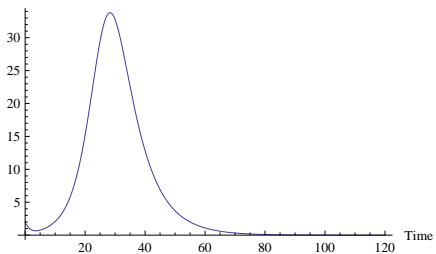
- 4 burrows, each one containing the model described earlier.
- Each prairie dog can travel from one burrow to the other.
- 2 prairies dogs and 10 fleas are infected in one burrow, all the other ones are healthy.

How is it modelled

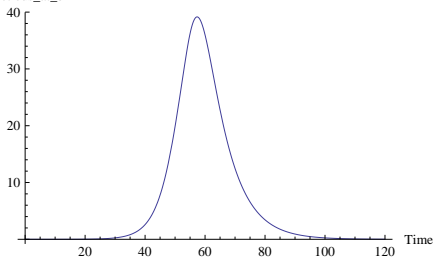


Graph

Infectious_at_b1

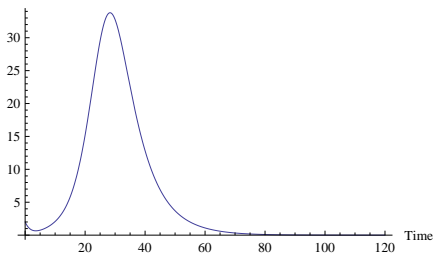


Infectious_at_b2

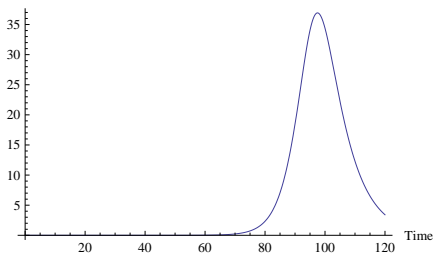


Why are ODEs not enough

Infectious_at_b1



Infectious_at_b4



How to use stochastic simulations

We cannot use stochastic simulations because the model is too big. However:

- We know how one burrow behaves.
- All we then need to know is the probability of movement happening from one burrow to the next.

Results

Prairie dog	Flea	% of infected burrows
0.001	0.001	56%
0.001	0	41%
0	0.001	40%

Conclusion

PEPA has proven to be a useful tool in epidemiology. Indeed:

- Most of the time, PEPA has been capable of dealing with the epidemiological problem it has been confronted to.
- Most of the issues (density dependent transmission, space, complicated models) can usually be dealt with.
- Also, having access to both the stochastic simulations and the ODEs has proven to be very useful.
- In the case of the prairie dogs, the ODEs were able to reproduce the results previously obtained, while the stochastic simulations showed that the ODEs were neglecting part of the problem.

Conclusion

However:

- PEPA might not be ideal when it comes to complicated models. Both ODEs and stochastic simulations may not be available.
- Sometimes, PEPA requires the use of non-biological way of modelling, for example for density dependent transmission.
- PEPA does not allow functional rate (for now?).

Questions

Any questions?