The Impact of Forest Roads on The Rate of Biological Invasion

UNIVERSITY OF BIRMINGHAM | BIFOR | The Forest Edge Doctoral Scholarship Programme

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Introduction

- Biological invasion of plant and tree species pose a major threat both to the ecosystem and economy [1].
- A significant amount of mathematical modelling has been conducted to simulate biological invasion [2].

Advantages of mathematical modelling:
- It is cheaper than field work
- Allows you to consider both small and large spatial scales of invasion
- It does not harm or disturb the environment in any way
  - It allows you to 'digitally' add an invasive species into an environment and investigate the consequences without introducing the invasive species into the real world
- We can predict (with reasonably good accuracy) the future spatial-temporal dynamics of the invasive species.

However, there is no 'universal' model of biological invasion.
Different models:

I. Partial differential equation based models (reaction-diffusion framework):
- Host-parasite
- Prey-predator
- Herbivore-grazer

II. Integro-difference equation based models (dispersal kernel framework)

Dispersal kernel based models are ideal for modelling plants, as the model:

Fig 1: Japanese Knotweed is a highly problematic invasive species, by DEFRA it is estimated the cost of total control across Britain is approximately £1.56 Billion [3]. **Image:** rhs.org.uk

- provides a more realistic description of the real world by simulating the stages of a plant's growth and dispersal
- treats the growth and dispersal stage of the plant independently
- allows modelling of long distance dispersal

Model

We will be using a stage structured dispersal kernel based model N

$$N(\underline{r}^*)_{t+1} = \int_{\Omega} k(\underline{r}^*, \underline{r}) F(N_t(\underline{r}))\, d\underline{r} \qquad (1)$$

- $\underline{r}^* = (x^*, y^*)$ - position where we can detect the invasive species
- $N(r^*)_{t+1}$ - the population density at r^* at time $t+1$ (to be computed from the model)
- $N(r^*)_t$ - the given population density at time t
- The population is stage-structured:

The growth stage - the population grows but there is no dispersal. The growth function is $F(N_t(\underline{r}))$.
The dispersal stage - the population disperses across the domain but does not grow. The dispersal kernel is $k(\underline{r}^*, \underline{r})$.

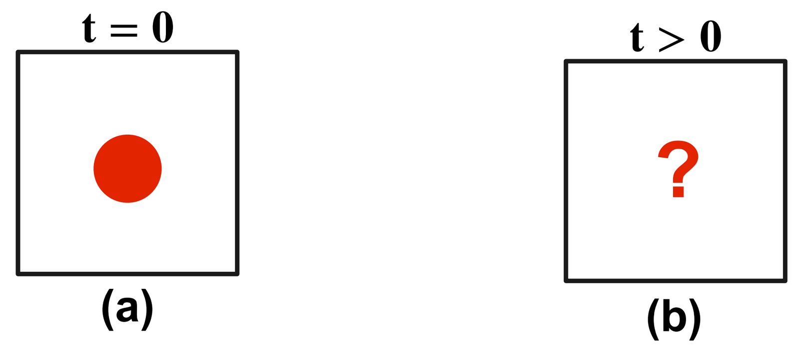


Figure 2: The summary of the invasion problem. **(a)** The initial distribution of the invasive species at time $t = 0$; the species is found in the small sub-domain (a red disk in the figure marks a region of non-zero density). The white colour in the panel corresponds to zero population density. **(b)** How will the invasive species spread over the domain as time progresses?

Previous Work

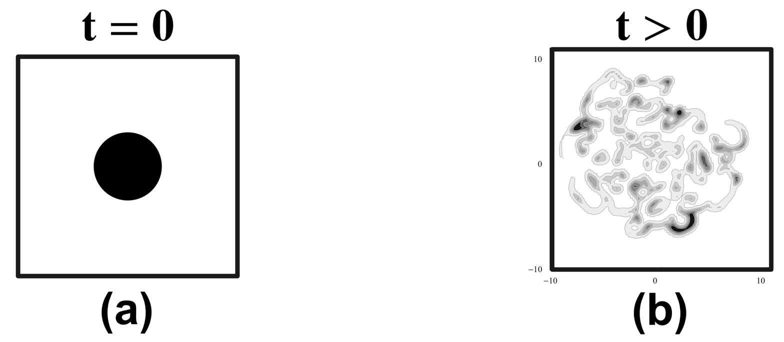


Figure 3: Example of spatio-temporal dynamics of the invasive species [4].

Stage structured dispersal kernel based models have already been used to model:
- Propagation of a single invasive species in 1 and 2 dimensions
- Interaction of an invasive species with another species (see Fig. 3)

However, the previous work assumes a simple domain geometry (no road!)

My Research

The Research Hypothesis:

- Roads provide an ideal environment for invasive species to spread [5].

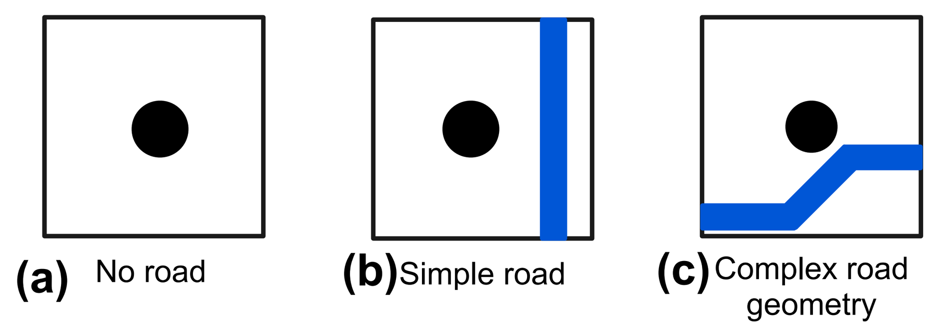
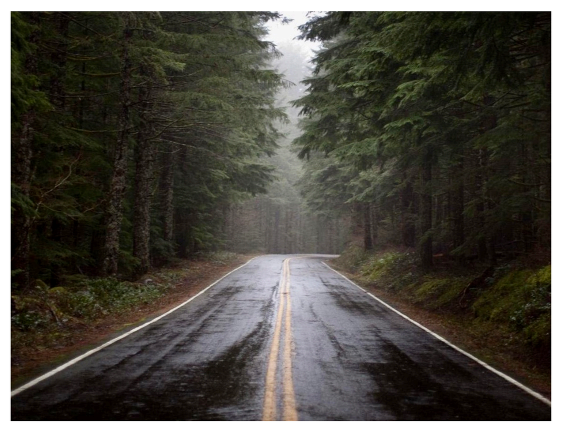
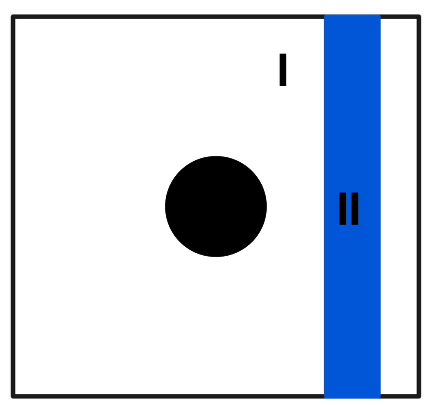


Figure 4: Various domain geometries (road is coloured in blue, a black disk marks a region of non-zero density).

Modelling: We use a different 'rule' of spread in the 'road' sub domain.





I. Slow spread of the invasive species in the region outside of the road

II. Fast spread of the invasive species in the region of the road

Figure 5: I - the forest sub-domain, II - the road sub-domain.

The different rule of spread is simulated by using different timescale and different dispersal kernels in the model

One-Dimensional Case

We first study the 1-D version of the model (1) to gain insight.

- The invasive species spreads along the interval $x \in [-L, L]$.
- The growth function is $F(N(y)) = 7N(y)\exp(-N(y))$
- The dispersal kernel is $k(x,y) = \dfrac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\dfrac{(x-y)^2}{2\sigma^2}\right)$, where $\sigma = 0.3$

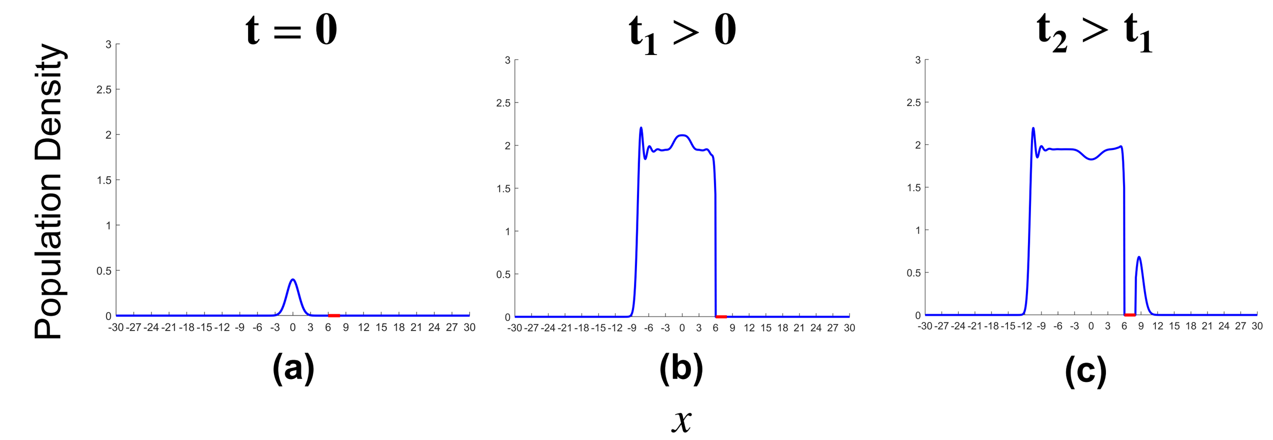


Figure 6: **(a)** Initial distribution of the invasive species, the 'road' is marked in red. **(b)** The population makes minimal interaction with the 'road'. The 'road' begins to make an impact on the spatial distribution of the invasive species: the overall symmetry of the population distribution has collapsed. **(c)** The area behind the road is now invaded.

Two-Dimensional Case

We then study the more realistic 2-D case using model (1).

- The invasive species spreads within the space $\underline{r} = (x, y)$, where $x, y \in [-L, L]$.
- The growth function is $F(N(\underline{r})) = 7N(\underline{r})\exp(-N(\underline{r}))$
- The dispersal kernel is $k(\underline{r}, \underline{r}^*) = \dfrac{1}{2\pi\sigma^2} \exp\left(-\dfrac{|\underline{r} - \underline{r}^*|^2}{2\sigma^2}\right)$, where $\sigma = 0.3$

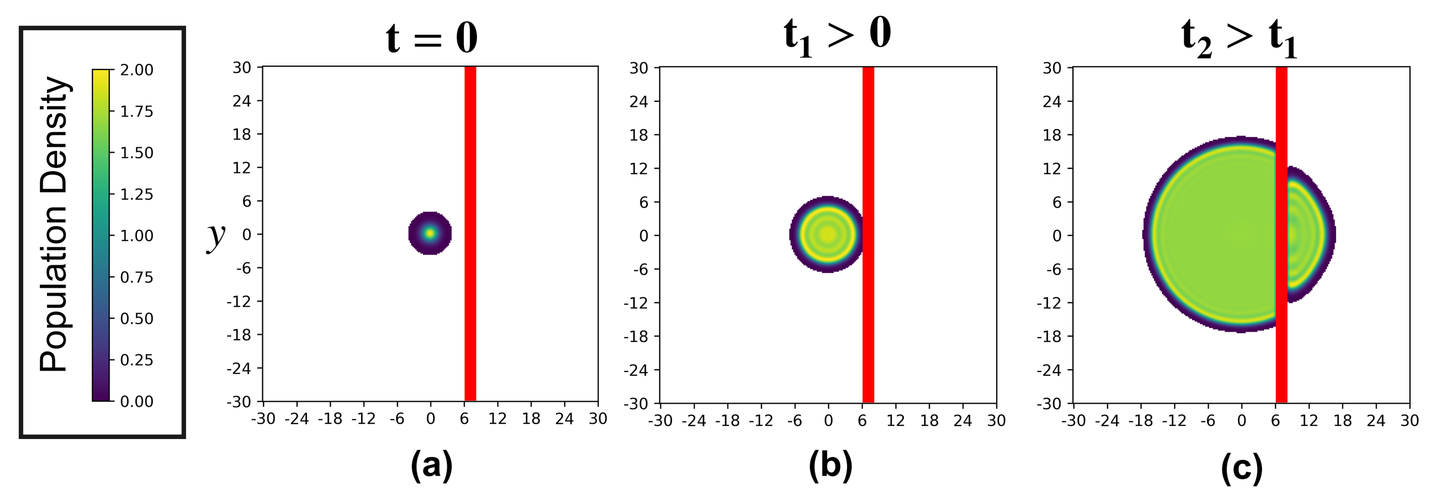


Figure 7: **(a)** Initial distribution of the invasive species. **(b)** The population reaches, but does not cross over the road. **(c)** The area behind the road is now invaded.

Current and Future Work

- Explore different growth functions, including Allee growth functions
- Investigate posible patterns of invasion
- Investigate the conditions needed for invasion to occur
- Study the 2-D problem
- Introduce complex road geometry

About the Author
My background is in applied mathematics. I am interested in the intersection of mathematics, computer science and nature.

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