The Impact of Forest Roads on The Rate of Biological Invasion

Bradly Deelely (bfs913@bham.ac.uk)
Forest Edge Doctoral Student, Leverhulme Trust
Supervisor: Natalia Petrovskaya

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)
Dispensal kernel based models are ideal for modelling plants, as the model:
- 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

My Research

The Research Hypothesis:
- Roads provide an ideal environment for invasive species to spread [5].

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!)

Model

We will be using a stage structured dispersal kernel based model

\[ N(y(t+1)) = \int k(x',y')F(y(x'))dy' \]

\( x' = (x,y) \) - position where we can detect the invasive species

\( N(x_i,t+1) \) - the population density at \( x \) at time \( t+1 \) (to be computed from the model)

\( N(x_i,t) \) - 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 \( F(y(x)) \).
The dispersal stage - the population disperses across the domain but does not grow. The dispersal kernel is \( k(x',y') \).

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 black colour in the panel corresponds to zero population density. (b) How will the invasive species spread over the domain as time progresses?

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].

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!)

Model

We will be using a stage structured dispersal kernel based model

\[ N(x_{t+1}) = \int k(x',x)F(N(t))dx' \]  (1)

\( x' = (x,y) \) - position where we can detect the invasive species

\( N(x_i,t+1) \) - the population density at \( x \) at time \( t+1 \) (to be computed from the model)

\( N(x_i,t) \) - 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 \( F(N(t)) \).
The dispersal stage - the population disperses across the domain but does not grow. The dispersal kernel is \( k(x',x) \).

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

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

Figure 5: (a) - the forest sub-domain, (b) - the road sub-domain.

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

Current Work

We first study the 1-D version of the model (1) to gain insight.
- The invasive species spreads along the interval \( t \in [-L, L] \).
- The growth function is \( F(N(t)) = 76(t)\exp(-tN(t)) \).
- The dispersal kernel is \( k(x',y') = \frac{1}{\sqrt{2\pi}} \exp \left( -\frac{(x'-y')^2}{\sigma^2} \right) \), where \( \sigma = 0.3 \).
- Questions to be answered in the 1-D case:
  - How fast does the population spread in the 'no road' domain?
  - How does the population spread in the presence of the 'road'?

Figure 6: (a) Initial distribution of the invasive species. (b) The invaded area grows as time increases. (c) Further growth of the invaded area, the spread rate of the invasive species is \( 0.0879 \).

- How does the population spread in the presence of the 'road'?

Figure 7: (a) Initial distribution of the invasive species. (b) The 'road' is marked in red. (c) The population makes minimal interaction with the 'road' (the density distribution is symmetric; cf Fig. 6).

- The 'road' begins to make an impact on the spatial distribution of the invasive species: the overall symmetry of the population distribution has collapsed. (d) The area behind the road is now invaded.

Future Work

- Explore different growth functions and dispersal kernels
- Study the 2-D problem
- Introduce complex road geometry

See https://bradlydeelely.forestedge.org.uk for more information.