# Dutch elm disease on the Isle of Man – Identifying 'danger-spots' using an agent-based model

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## 1. Introduction

The paper proposes an agent-based model of the spread of Dutch Elm Disease (DED), applied to a case study of the Isle of Man (IoM). This self-governing Crown Dependency, midway between England, Scotland and Ireland, has an estimated population of 250 – 300,000 elms, and is one of the few areas in Europe where disease has not yet become endemic. The aggressive form of Dutch elm disease was first discovered on the Isle in 1992, transmitted by two species of the bark beetle *Scolytus*. In contrast with the British mainland, where the disease was soon permitted to run wild, destroying around 30 million trees since the late 1960s, the Manx authorities set up a strict, and hitherto quite successful, control program, restricting total recorded losses and preventative fellings to date to around 1,000.

Whilst the epidemiology of the DED has been largely studied and the lifecycle of the disease is by now well known, most on DED studies are essentially *aspatial*. Models of the DED have been developed, focusing on either the biological aspects of the disease – (see Castro and Bolke's (2004) study on parasite dynamics) or on the spread of the disease (see Swinton and Gilligan, 1996).

The present study proposes a three dimensional agent-based-model (ABM) as an approach to identifying DED danger-spots on IoM. If successful, the model would help the identification of the locations on the IoM where outbreaks might lead to the greatest mortality among the Isle's elm population, and thus help the control of the disease.

The agent-based model creates an appropriate three-dimensional environment to emulate a real-world scenario, where agents and environment can interact. The model simulates the spread of the disease by using a digital elevation model of the IoM's terrain and randomly generated data for elm trees, beetles, foresters and birds – all of which which are known agents in the spread of the disease. The study focuses on effects of geospatial elements, in particular elevation, on the dynamics of the spread of DED.

The paper presents the development of the model's prototype, which has been developed using StarLogo TNG (MIT Media Laboratory, 2008) due to its fast and easy implementation as well as 3D modelling support.

## 2. The DED Model

The model simulates the landscape dynamics through interaction of agents. Individual agents are use to represent different groups such as beetles, trees, and woodsmen within a modelled 3D environment (see Figure 1).
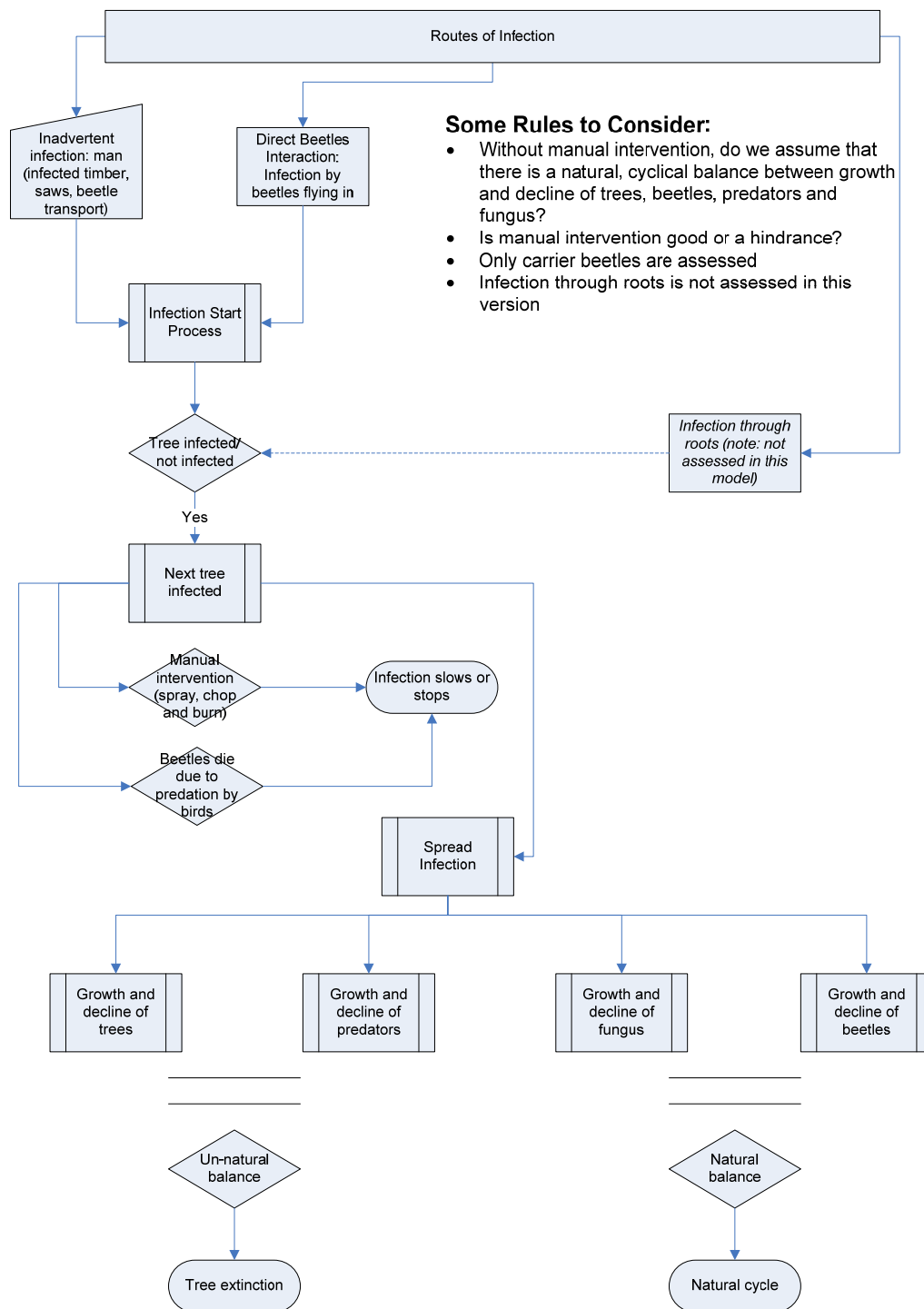
**Figure 1: Agents Forester, Boid (blue), Beetles (black), and Elm.**

In the model, each raster cell obtained real-world equivalent dimensions of circa 400 metres along both axes. In this environment, each agent presents a different behaviour which replicates DED's real-world dynamics. Elms, Foresters, Boids and Beetles are deployed: Beetles seek out and infect Elm; Foresters seek to fell diseased Elm before the next generation of Beetle hatches. Boids pursue and eat Beetle on the wing. The behaviour of each agent and their interactions is shown in Figure 2.

The activities of the agents are governed by random probability. Where appropriate, this is modified by a 'sense' of where their prey is, governed by a 'smell list' function within the model. Each simulation run does not represent any particular unit of time.

The model has twelve user adjustable variables, which were fine-tuned and locked down to optimum settings. Interaction of all agents was carefully calibrated to optimise performance and stability.

Routes of Infection

Inadvertent infection: man (infected timber, saws, beetle transport)

Direct Beetles Interaction: Infection by beetles flying in

**Some Rules to Consider:**
- Without manual intervention, do we assume that there is a natural, cyclical balance between growth and decline of trees, beetles, predators and fungus?
- Is manual intervention good or a hindrance?
- Only carrier beetles are assessed
- Infection through roots is not assessed in this version

Infection Start Process

Tree infected/ not infected

*Infection through roots (note: not assessed in this model)*

Yes

Next tree infected

Manual intervention (spray, chop and burn)

Infection slows or stops

Beetles die due to predation by birds

Spread Infection

Growth and decline of trees

Growth and decline of predators

Growth and decline of fungus

Growth and decline of beetles

Un-natural balance

Natural balance

Tree extinction

Natural cycle

**Figure 2: DED Model flowchart**

## 3. The impact of the landscape on DED dynamics

The idea explored by this study is that Scolytus beetles do not fly much beyond the tree-line for elms and, therefore, landscape of sufficient height can consequently act as a *cordon sanitaire* for DED control strategies.

On the Isle of Man two ranges of hills exceed the local natural tree line for elms. So, infestations originating in one part of the island might be contained, or find easy passage to beyond. This will produce a correlation between original epicentres of infection and the number of elms destroyed.

The maximum elevation to which elms will grow has been fixed at 160 metres, and a ceiling has been set for on beetle flight which is 25 % higher (200m). This placed elevation at the model's centre.

A binary raster was created in ArcGIS to reflect whether the modelled terrain permits passage by the modelled beetles (see Figure 23). A Raster Cell Neighbourhood Statistic (RCNS) was calculated to represent the degree of openness of any given cell to being traversed by Agent Beetle and, consequently, the level of risk of any local Agent Elm.

When the RCNS is calculated and the zones classified in eight natural breaks, the most vulnerable class of zones forms five regions (Figure 3). Disease may potentially spread widely within the two largest regions, but transit *between* these two regions will be more difficult, as the beetles will have to pass through zones with lower RCNS values.
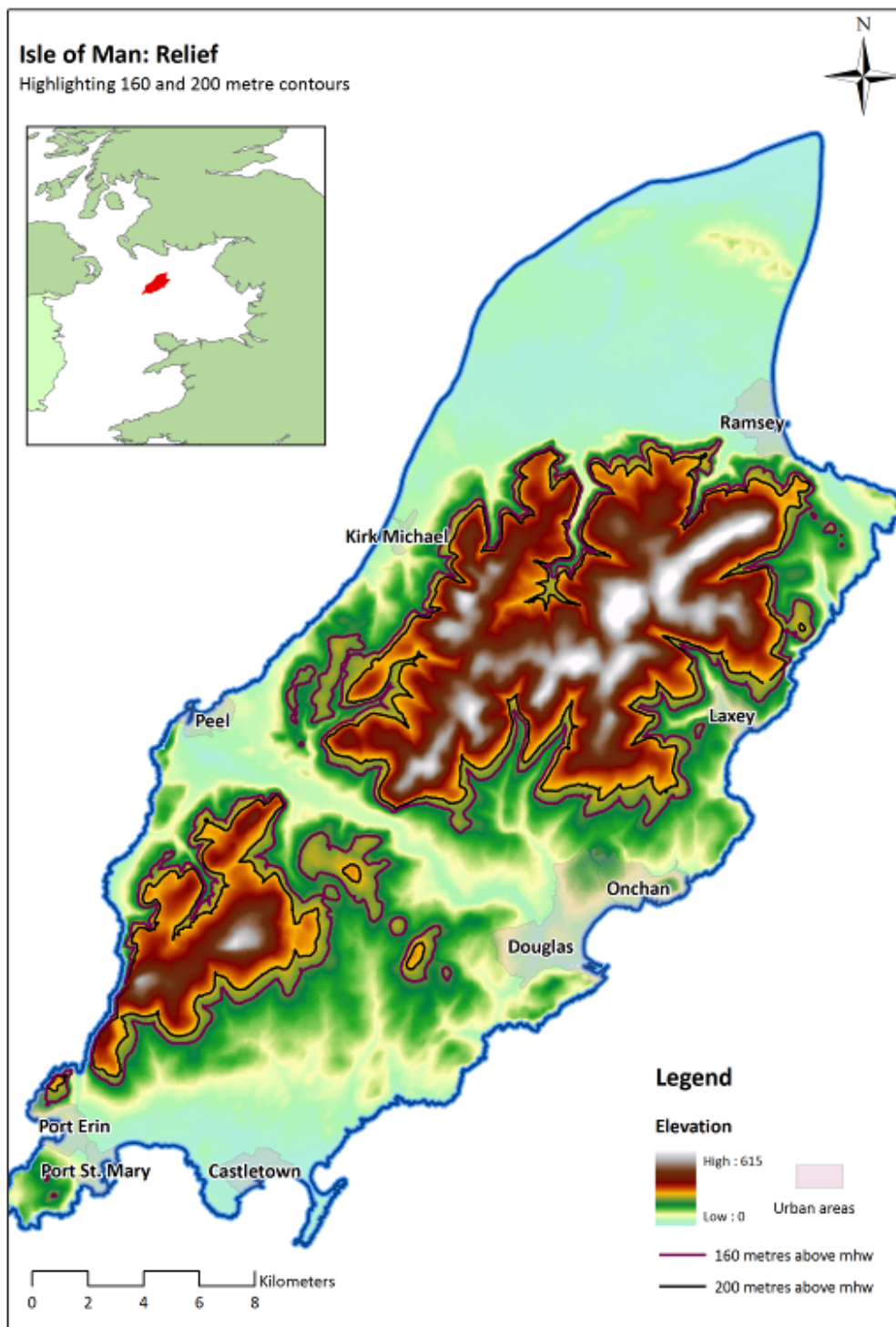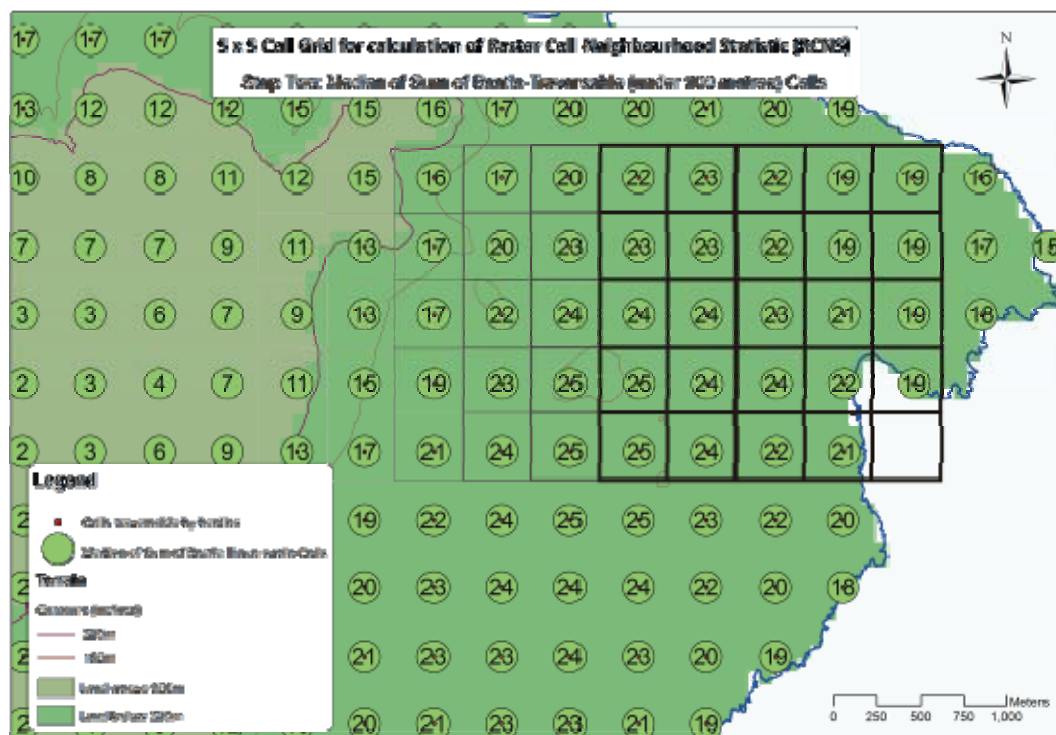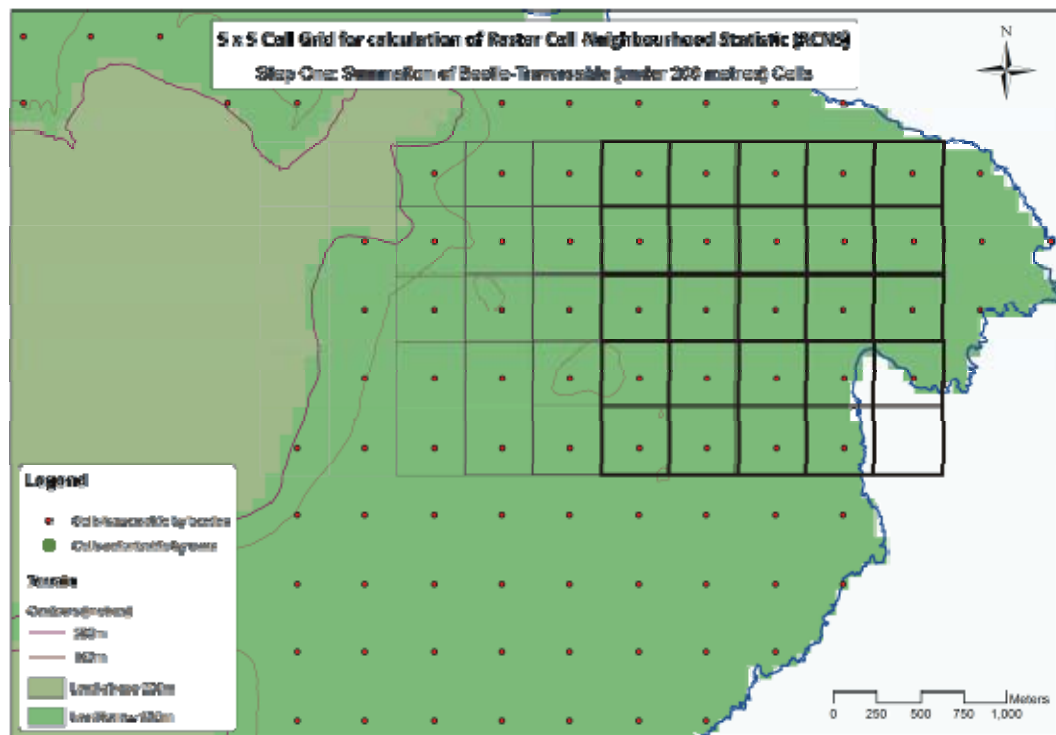
**Isle of Man: Relief**

Highlighting 160 and 200 metre contours

N

Ramsey

Kirk Michael

Peel

Laxey

Onchan

Douglas

Port Erin

Port St. Mary    Castletown

**Legend**

**Elevation**

High : 615

Low : 0

Urban areas

—— 160 metres above mhw

—— 200 metres above mhw

Kilometers
0    2    4    6    8

**Figure 2: Isle of Man: location and relief**

**Figure 3: RCN Statistic**

## 4. Discussion of results

The TNG model was run successfully 106 times to generate results for many areas, and obtain a distribution of results. The great majority of successful infestations began in zones with the highest RCNS. This is partly a function of the RCNS's construction.

Four locations tend to be picked up more frequently in beetle cluster buffers: near Douglas, north of Castletown, south of Peel and, most prominently, in the northern plain (Figure 5).

**Error! Reference source not found.** displays the number of elms that survive to a run classified by standard deviations from the overall mean number of survivors. A distinct pattern is observable, with low survival rates around Douglas, average rates in the north and high rates near Peel, south of Ramsey and in the further south.

Figure 5 shows the average number of elms that survive to a single run when the given cell is in a beetle cluster. The darker shades signify areas which produce the highest mortality, and are therefore the danger-spots we have been looking for. It highlights three locations.
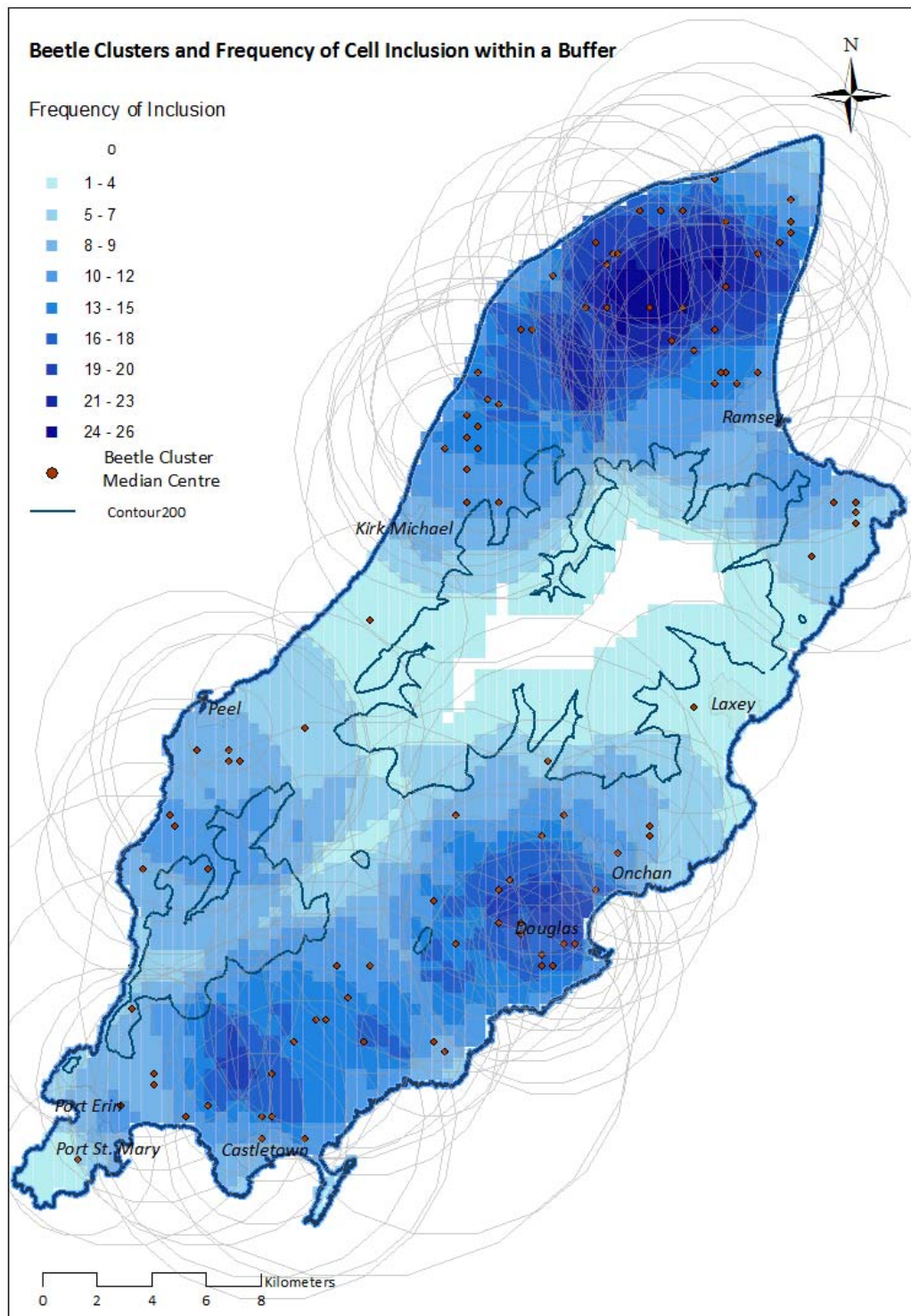
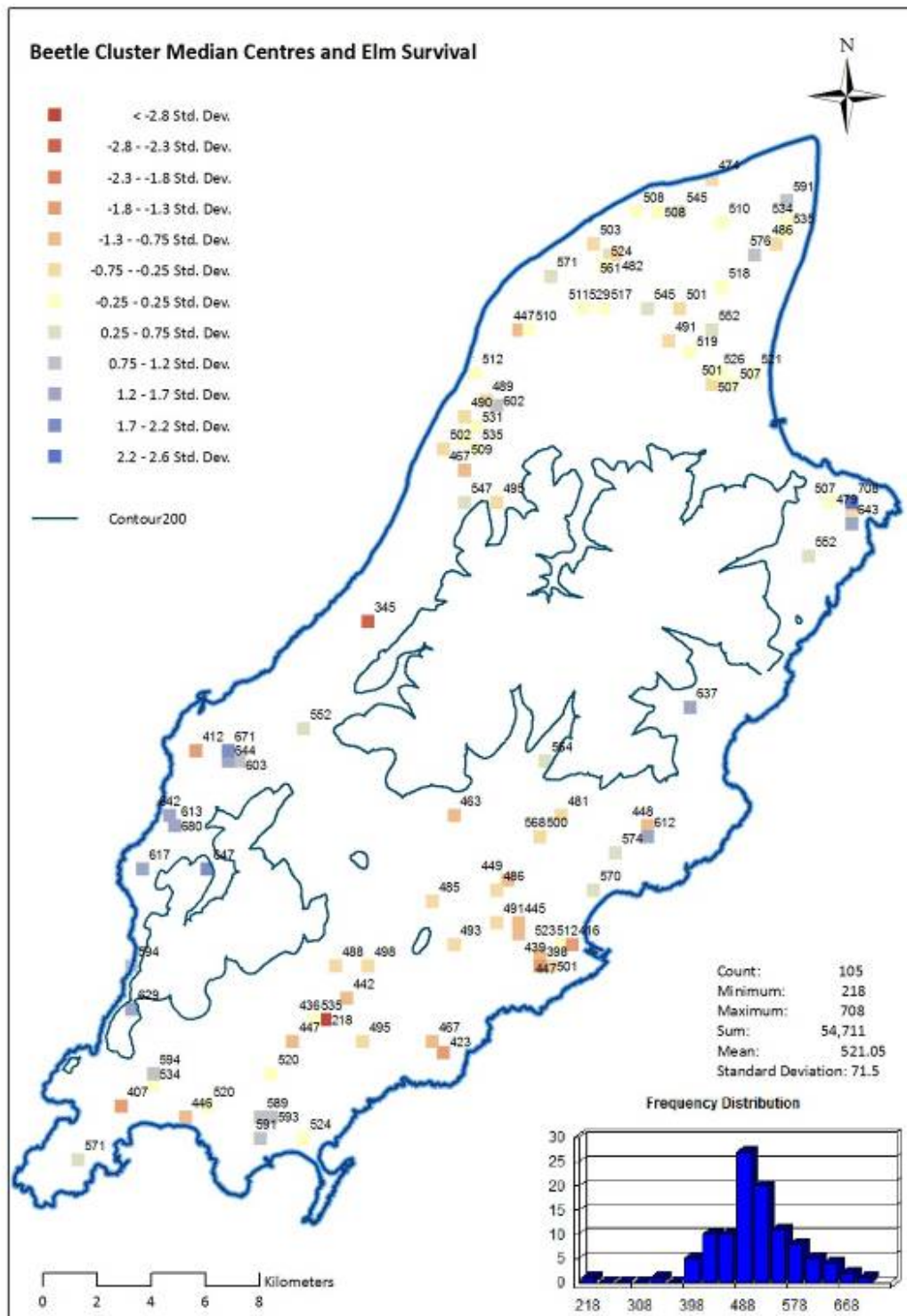Figure 5: Beetle Clusters and Frequency of Cell Inclusion within a Buffer

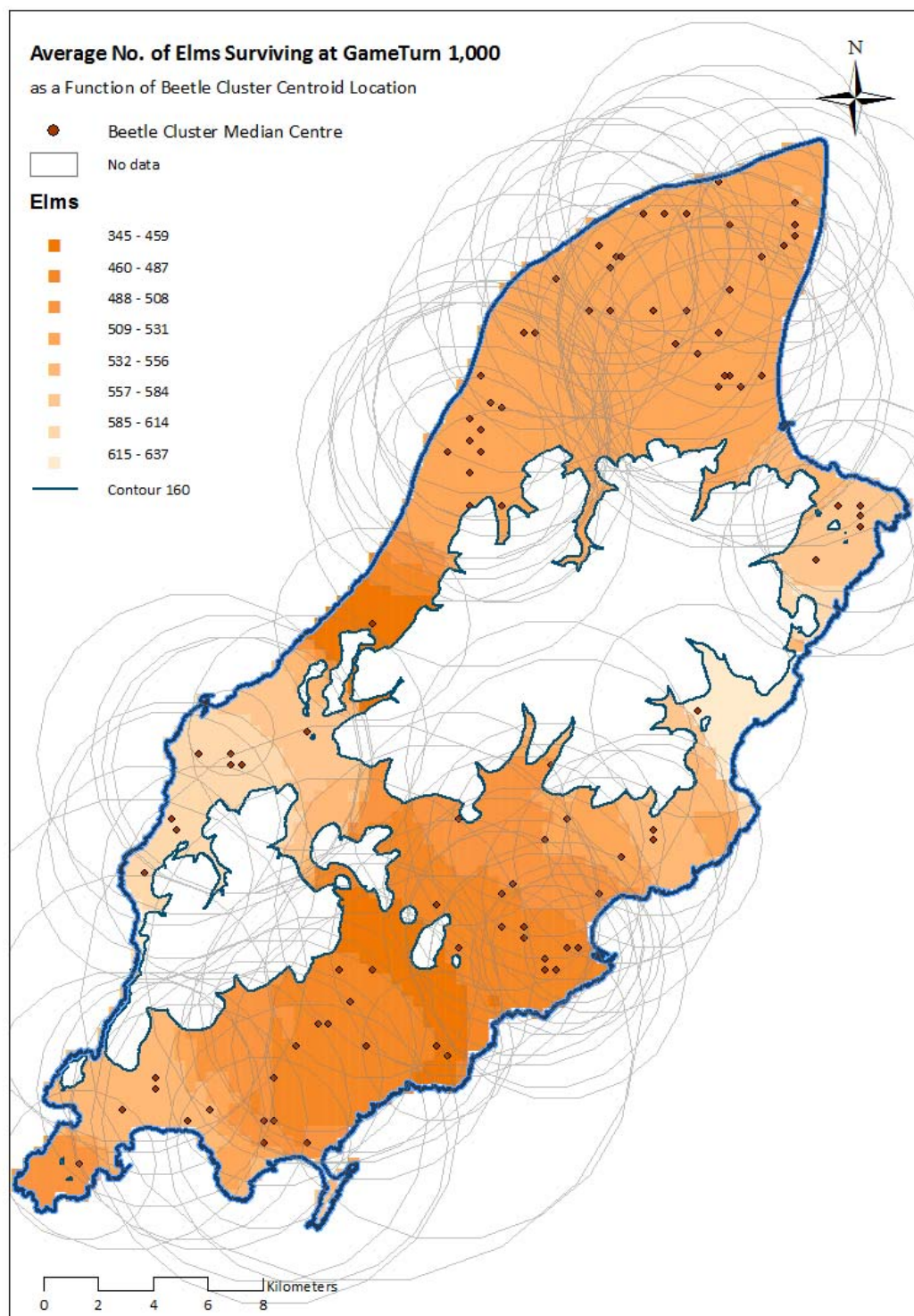Figure 6: Beetle Cluster Median Centres and Elm Survival

**Figure 7: Danger-spots - Mean number of elms surviving as function of cluster location**

## 5. Conclusions

Despite only being a prototype developed in StarLogo TNG, the DED model has been described by the designers of StarLogo TNG as "one of the biggest projects the software has ever been used for" and one which pushed it "beyond what it has so far been used for" (Daniel Wendel, personal correspondence). It has shown StarLogo TNG to be capable of modelling real-world systems and running a complex three-dimensional model which can be connected to GIS software.

Despite the early stage of the project and the small number of data runs being produced, preliminary results conform to the expected pattern – that parts of the island (in the presence of a randomly distributed elm population and the absence of local climatic variations) may be more conducive to beetle generation and the onward spread of Dutch elm disease than others.

Future research includes the further development of the model in order to achieve more realistic results. This includes the use of a more established agent-based modelling framework such as REPAST (University of Chicago). The final objective of this study is to provide the Manx forestry authorities with a more refined and realistic tool which can be used in their campaign to keep the disease at bay.

## 6. Future Work

Elimination of all non-essential variability; acquisition of real data; fixing data to constant between runs.

Enable thousands of runs, probably through re-write in University of Chicago's RePast

Possible extention to other areas involved in the fight against DED. It could be adapted to other forest pathogen systems for which elevation is an issue. Elevation could indeed be replaced by one or more different factors.

# 7. References

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