How important are trees for our planet?

Trees are one of the most important elements for maintaining the climate and ecology of our planet. They are also enormously important for the well-being of humans. Some of the reasons why trees are so important are:

A street tree planted and maintained by our home education group.

- Trees are the lungs of our planet. They provide up to 50% of the planet's oxygen. Trees also absorb carbon dioxide and when fossilised, lock carbon away in the earth. This helps to regulate greenhouse gases and maintain the climate of the Earth.
- Trees provide habitats for thousands of animals, insects and fungi. Every part of the tree can form a habitat – even the dead parts on the ground.
- Trees have an important role in preventing flooding. They intercept rainfall reducing the run-off on the ground and they stabilise the soil preventing erosion.
- Trees absorb air pollution helping to provide cleaner air for cities resulting in reduced rates of asthma, strokes and heart attacks. They also provide shade for buildings, helping to reduce the need for air conditioning by up to 30%.
- Studies show that trees can reduce the crime rate of a neighbourhood by around 7%. This could be due to increased pride in the neighbourhood or better mental health created by humans having exposure to the natural environment. Trees also make great play areas for children, giving them opportunity to learn how to use their bodies and increase their physical fitness.

Activity

Look outside. See if you can locate a potential site for a new tree.

If a tree was planted there, what benefits do you think the new tree would bring to the local environment?

Tree diseases

Dutch Elm Disease has almost totally destroyed mature Elm trees in the UK, and there are a growing number of new epidemics, such as *Chalara fraxinea* (Ash Die-back), that now threaten other major tree varieties. Every continent, despite the diversity of trees to be found, is affected and given the importance of trees to our well-being, this is a huge global threat.

There are many reasons for the recent rapid spread of tree diseases which include;

- Transportation of trees and therefore diseases and pests
- Global warming which affects lifecycles of pests as well as the tree lifecycle itself
- Monoculture of some forests
- Less genetic diversity of some species
- Rapid spread of disease with no time for natural immunity to evolve
- Movement of people around the globe, therefore movement of contaminated material e.g. on footwear

Activity

Think about how a government could legislate to reduce some or all of these factors.

***Chalara fraxinea* infected 10KM squares:**

Year	Number of new infected squares
2012	89
2013	68
2014	203
2015	373
2016	414

Look at the data demonstrating the spread of *Chalara fraxinea* in the UK. Can you describe the distribution of the first infected areas?

Do you think we can identify roughly where the first case or cases may have been located?

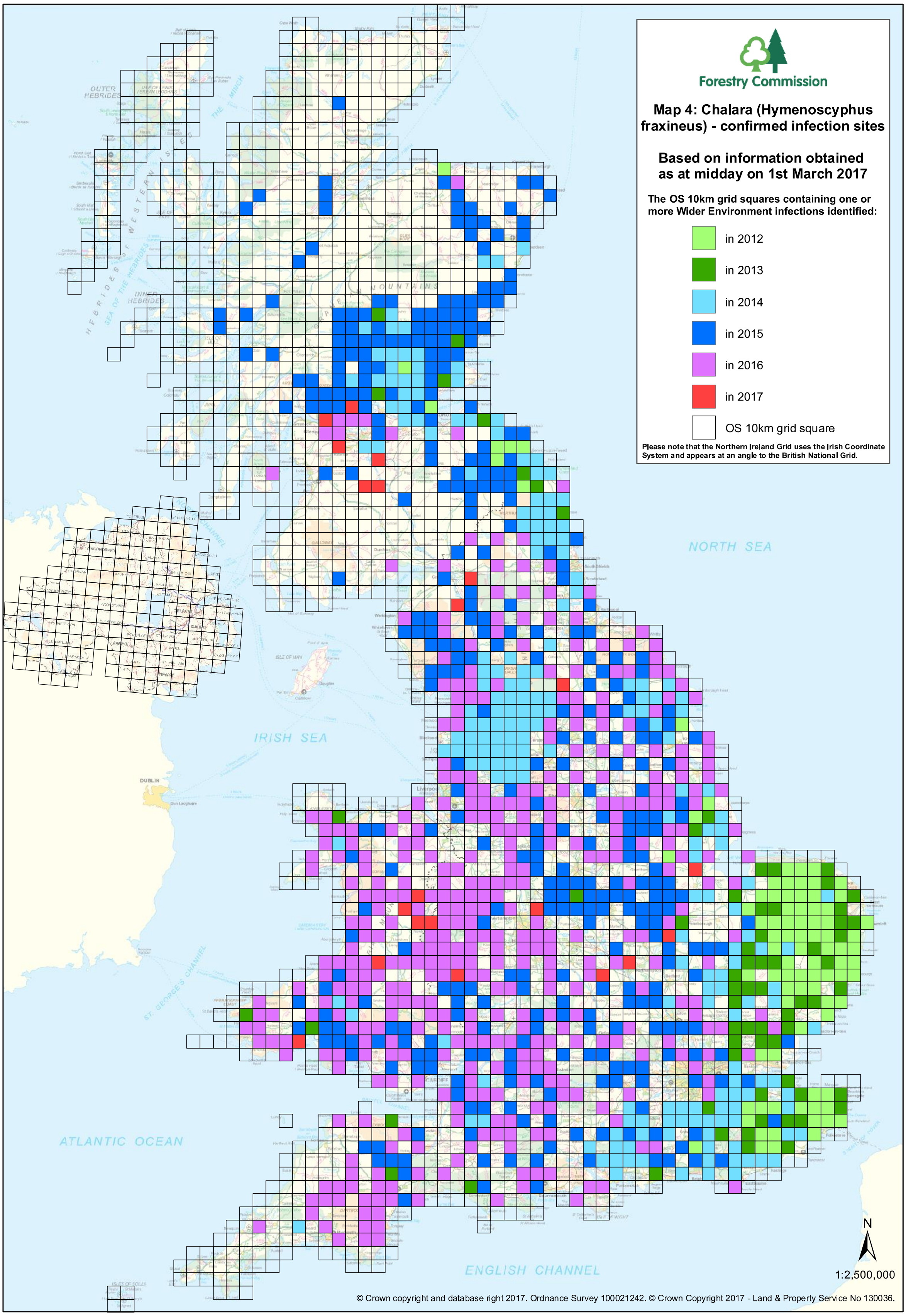
How would you describe the spread of the disease?

Can you work out the average number of new squares identified as having the disease each year from the data below (extracted from this map) from 2012 to 2016?

The UK is divided up into an estimated 2500 10x10KM squares. What is the rate of infection in 2012 and in 2016?

Do you think these data provide an accurate picture of the actual numbers of new infections?

What would you estimate the rate to be in 10 years time?



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Modelling the spread of tree diseases using maths

Mathematical modelling is a useful tool for studying complicated systems and the effects different components may have on them. Forests are extremely complex environments, there are many different tree diseases and they can be spread in many ways. However, using models we can explore aspects of transmission and look at what the effects might be. By comparing these models to observed disease spread we may be able to make conclusions about factors that contribute to a greater or lesser degree. This may help us predict trees that are at risk and identify major mechanisms of spread and in so doing possibly protect our trees in the future.

Activities

Build a simple model forest

- You will need a piece of paper, 2 dice and a counter.
- Draw a 12 x 12 grid of squares on the paper, as large as will fit.
- Label both the x and y axis from 1-12.
- Throw the dice and add up the values to get the x co-ordinate, then throw again (and add) to get the y co-ordinate. In the square identified, draw a simple shape to represent the first tree, which will be our index case (source of infection), and mark this with a cross.
- Now throw both of the dice twice again to locate the square for our next tree.
- Now throw a single die and move the counter from the index case towards the second tree moving one square at a time to any adjacent square (not diagonal) for the number of moves on the die, e.g. means move 2 squares. Can you calculate the probability that the second tree will be reached with 2 throws of the die? For example, if the second tree is adjacent to the first then it will be 100%, if it is 2 squares away it will be 92%.
- This model represents the effect of distance has on the spread of infection. The further away a tree is, the less likely infection will spread to it, hence currently less disease in northern Scotland.
- Add a footpath across your grid (represented by a line that starts at one edge and finishes at another). Plot another tree using the dice as before. When you throw the single die now, if you can reach this line during your move you can move along it as far as you like towards the newly plotted tree (without using any additional moves) and then continue from another point along it. How does this alter the probability of the spread of infection to this tree? This represents the effect of footfall disseminating infection e.g. by the transfer of spores in soil/mud on shoes of visitors to the woodland.
- How many mechanisms of disease spread can you identify? Can you think of a way to add any of these other factors into this model, for example spread by wind (in a north, east, south or west direction)? How does this alter the probability of spread?

In exploring these factors in our model we designed a board game that can be found on this site. There is a description of how to make and play the game, which takes this activity one step further. To make it more exciting it is a two-person game that adds complexity in the form of natural tree immunity, which is how we hope our trees, will combat the spread of disease in the future.

Using Python to model the spread of tree diseases.

Dutch Elm Disease

Our first model charts the spread of a tree disease similar to Dutch Elm disease. In the case of this disease the trees in the population have a low genetic diversity and therefore no immunity to the disease. The disease is spread by beetles which carry fungal spores. The current contagious strain of the disease arrived in Britain in 1967 and had killed the vast majority of Elm trees in Britain by 1990 (although the disease is still spreading in Scotland).

The program charts the spread of the disease from one selected tree (coloured red on the map). A random number is generated (from 1-6 to emulate the roll of a die). Depending on the outcome, a radius of infection is chosen, for instance, if a '1' is generated, then the radius of infection is 1.9m, a '2' creates a radius of 2.4m and a '3' creates a 1.5m radius.

The program iterates through the list of infected trees and tests whether a healthy tree is in the infection radius using the following equation:

$$d = \sqrt{(x_p - x_c)^2 + (y_p - y_c)^2}$$

Where 'd' is diameter of the circle, x and y (p) are the coordinates of the healthy tree and x and y (c) are the coordinates of the infected tree.

'r' is the radius of the circle. If d <= (smaller than or equal to) r, then d is within the radius of the circle, or on the edge of the circle, and therefore the healthy tree can be infected and changes from green to red.

If a '4', '5' or '6' are rolled then another random number (from 1 to 6) is generated. If this second number is equal to 2 then a random healthy tree, anywhere on the map, is infected. This is to model the arrival of additional insects from elsewhere.

Activity

At the moment, the program has a constant rate of infection. Can you think a way to alter the infection rate so that it peaks over the months of May and June (research shows that this is when Dutch Elm beetle is most active and therefore the rate of infection is highest)?

Can you alter the probabilities in the program to model the spread of a less infectious disease?

You can find the source code in the file named 'main.py'

Chalara

Chalara is spread by fungal spores and causes die back in ash trees. However ash trees have a much greater genetic diversity, and it is thought that the natural population of ash trees will have some immunity to this disease - somewhere between 5 and 10%.

The program here has been altered to make 10% of healthy trees immune, or rather, upon start-up, each healthy tree has a 10% chance of becoming immune. We achieved this by iterating through the list of healthy trees, and generating a random number between 1 and 10 for each tree. If this number is a 3, then that healthy tree then becomes immune and is ignored by the disease. The trees with immunity are coloured blue.

When this program is run, you can see that the rate of infection over the whole map is slowed down. This is because the immune trees act as a kind of barrier against the spread of infection because these trees can't be agents in the spread of the disease.

<u>Activities</u>

Can you think of a way to alter the program, so that the natural immunity is 5% of trees?

You can find the code in 'main.py'

How do you think this would alter the rate of infection?

Human activity and the spread of Chalara

The Chalara spores are spread mainly by wind but can also be spread through an area of woodland by human footfall – people walk through a wood and carry fungal spores on their shoes and clothing.

This version of the program includes a path, which is used regularly by humans. This functions much like a long chain of infection through the map. The infections caused are counted as infected trees, which use the infection loop in the program to infect healthy trees just as normal.

The program utilises a file, which plots the line of the path through the map.

To infect healthy trees, the program iterates through the list of the path's points and checks whether a healthy tree can be infected by one of these points, using the same equation as used before with the infected trees, but within a set circle radius of 2m. If a path point can infect healthy trees, it does so, infecting all healthy trees within its circle of infection. Then the infection can spread from these infected trees, in the usual way.

As you can see, the rate of infection is somewhat increased by the presence of the path.

Activities

Could you change the coordinates of the path so that the rate of infection impacts minimally on the standard rate of infection?

You can find the list of co-ordinates in the file named 'path.txt'

Can you see how this information would be useful to woodland managers when planning paths?

Human activity and natural immunity

Our last model shows the spread of Chalara through a wood with a population of trees with 10% natural immunity and with a pathway running through it.

This is an amalgamation of the two previous programs. Upon running the program, you can see that natural immunity and human footfall cancel each other out to some extent. However, this entirely depends on the path coordinates. For example: If the path reaches trees which were hard to infect for the disease, then infection rate is increased, but if the path is in a place where it can't infect many trees, then infection rate in decreased.

There are many other factors that have to be considered when attempting the spread of a tree disease such as Chalara. Other factors include temperature, rainfall, wind direction and speed, the use of infected tools and the planting of saplings which are already infected.

Activities

Think about how the strength and direction of the wind could affect the spread of Chalara.

What about the use of infected tools?

Can you think of a way to alter the program which would model the effects of one of these infection methods?

What else would you need to know in order to create the most accurate model possible?