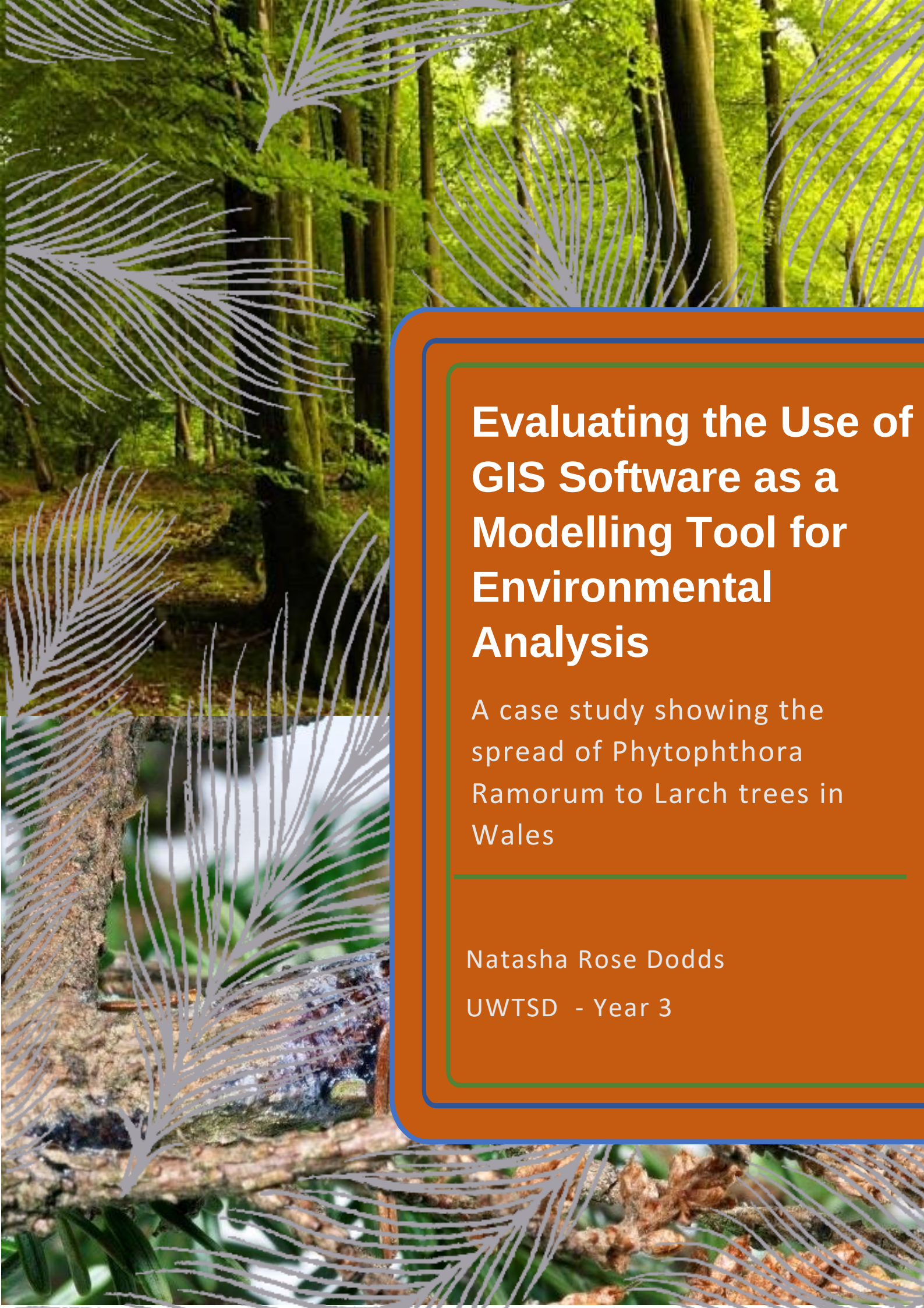


The background of the slide is a lush green forest. In the lower-left corner, there is a close-up photograph of a larch tree trunk, showing a dark, irregular lesion caused by Phytophthora ramorum. Stylized, light grey fern fronds are overlaid on the image, particularly on the left side.

Evaluating the Use of GIS Software as a Modelling Tool for Environmental Analysis

A case study showing the spread of *Phytophthora Ramorum* to Larch trees in Wales

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UWTSD - Year 3

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Abstract

This research looks into the spread of Phytophthora Ramorum to varying species of Larch in Wales between the years of 2010 and 2014. Through the use of Geographical information systems and varying sets of geospatial data, conclusions were able to support the literature found implying that Phytophthora Ramorum was likely spread via water and through the use of statistical modelling this can be shown in a timely and accurate manner utilizing software such as Mapinfo and Excel.

1.0 Introduction to GIS

Geographical information systems are frameworks to analyse, store and visualise data collected from geographical locations. They are the evolution of traditional cartography sharing a fundamental similarity, utilization of a base map. The difference is that GIS maps can store limitless amounts of data and can enable statistics and analysis to present data to support particular scientific or social arguments (Dempsey, 2012). GIS enables examination of spatial relationships, trends and patterns and connects geography with science and technology. GIS is increasingly important in environmental monitoring as the ability to view and analyse this spatial data on a map helps to better understand these patterns and trends to make more informed decisions on data collected, in a simpler, faster and more accurate way (Esri, 2018b). This research provides sustenance to the data regarding infected trees provided by the forestry commission Wales. Through the use of GIS the research aims to highlight any patterns found and link these to causation through research of established literature.

1.1 Introduction to Phytophthora Ramorum 1.1

Phytophthora Ramorum (PR) is an organism similar to algae called a water mould. It is classified as a pathogen and has been known to affect over 150 plant and forest species (Chadfield and Pautasso, 2012; Forest Research, 2019) Phytophthora Ramorum was first found in South Wales on larch trees in 2010 in the Afan Valley and is thought to be one of the most serious diseases to affect Welsh forestry. Larch trees represent around 7% of Welsh woodland, over 23,000 hectares (Warren-Thomas and Henderson, 2017) and though the disease does not affect the timber of larch trees it has had serious consequences for the forestry industry in Wales with regional and local economic impacts. Since the beginning of the spread from 2010 to 2015 over 6 million trees have been infected. In 2012 the wetter than average conditions likely aided the increased dispersal of the disease, as in 2013 three million trees were infected. (Venette and Cohen, 2006; King, Harris and Webber, 2015) The pathogen is thought to spread via water and prefers wet and windy conditions which help the sporulation rates and allow the pathogen to be spread further. Since 2010 disease management zones have been designated and over 23,105 hectares of larch designated within the control zones (Assembly Wales, 2018)

1.2 Research Aims

- To understand whether the use of GIS software and geospatial data can help support literature found regarding the Phytophthora ramorum tree disease spread to Larch trees in Wales
- To utilize data provided by the Forestry Commission in Wales to investigate ways of mapping, visualising and building GIS models that could be used to monitor and control the spread of the Phytophthora ramorum disease and perhaps help lessen the impact on the environment
- To bring together existing literature to analyse through the use of GIS the spread of GIS over specific time periods to add to existing research ways to minimize the social, economic, environmental and cultural impacts of P. ramorum

1.3 Objectives

- Research a variety of resources and build a case study on the spread of Phytophthora Ramorum
- Utilize Map info and a variety of software programs and resources for spatial analysis and statistical modelling
- Build a geographical information system to support my findings regarding the Phytophthora ramorum tree disease spread to Larch trees in Wales
- Identify whether there are patterns to the pathogens spread that can be identified through the use of GIS.

1.4 Hypothesis

1. There are patterns to the spread of P.Ramorum to larch in Wales through water
2. There are patterns to the spread of P.Ramorum to larch in Wales through recreational and human footfall

2.0 Literature Review

2.1 History of GIS

In 1854 a cholera outbreak incited a doctor named Jon Snow to map the outbreak locations along with the property boundaries, roads and water pumps which helped the discovery that the disease was in fact spread via water and not airborne, as initially perceived, and even indicated a specific water pump (Steenson, 2019). The map (fig1) was a colour graded map, which highlighted the 48 districts and is considered the first spatial analysis map (Dempsey, 2012). This was the early beginnings of spatial analysis and the linking 'what' with 'where' (Steenson, 2019). Spatial analysis is defined as "a research paradigm that provides a unique set of techniques and methods for analysing events—events in a very general sense—that are located in geographical space" (Fischer, 2001).

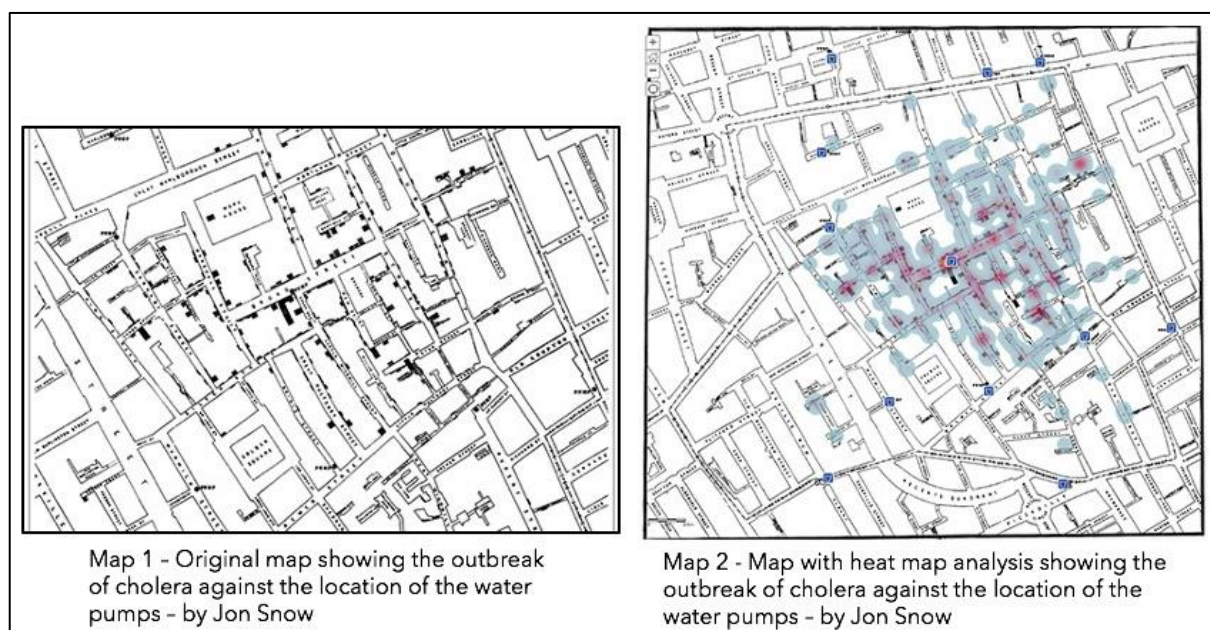


Figure 1 Maps depicting original map by Jon Snow

The field of GIS began as early concepts of computational and quantifiable geography emerged, during the 1960's. Michael Goodchild of the National Centre for Geographical Information and Analysis provided essential research along with the academic community on science topics such as visualization and spatial analysis which prepared the groundwork for GIS (Esri, 2018b). In 1963 Roger Tomlinson pioneered work to develop the Canada Geographic information system which was the first computerized GIS system created. Tomlinson's design enabled automated computing to store and process data, which had been commissioned by the Canadian government to create an easy way to manage their inventory of national resources and begin a national land use and management program (Esri, 2019).

Three important technological advancements occurred during 1960 and 1975 which provided the ability to record co-ordinates as data and perform calculations on them, leading to the birth of modern GIS. The three advancements are listed below.

- the ability to output map graphic using line printers
- advances in data storage
- advances in processing power of mainframe computers

During this period Jack Dangermond, co-founder of Esri Inc developed the first vector GIS called Odyssey GIS from his laboratory at Harvard. By the late 70's computer memory and improved graphic capabilities led to the creation of commercial GIS software. Esri, which is one of the largest companies in the world when regarding software, played a key role in its development and history (Esri, 2015).

2.2 GIS and Environmental monitoring

GIS provides the ability to aggregate data from a variety of inputs, which when considered in map format can be a useful and important method to increase general awareness of environmental conditions and issues and help to enable accurate decision making. GIS has the ability to present environmental data as maps or graphs through classification, visualisation and symbolisations, helping scientists and users to draw conclusions about the data (Larsen, 1999). Spatial analysis is the stacking of layers (fig 2) containing different strings of data which enable comparison with each other based on location. The layers are georeferenced and true to geographic space (Esri, 2018a).

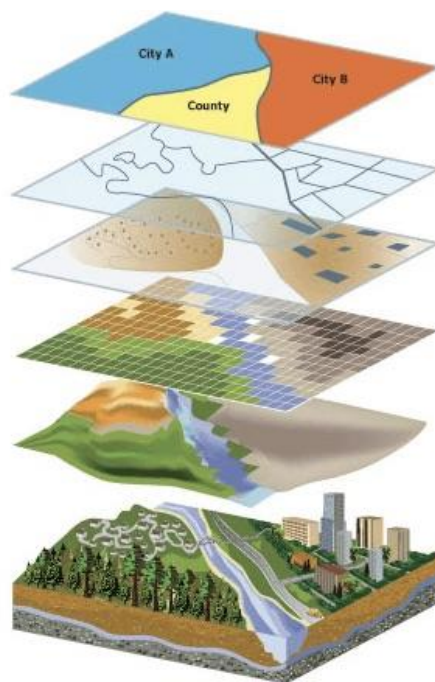


Figure 2 Diagram showing varying spatial layers to a GIS - Esri, 2019

2.3 Phytophthora Ramorum

Phytophthora Ramorum is an organism similar to fungus, affecting a wide range of species, this deadly tree pathogen was first discovered in 2002 in Sussex at an ornamental nursery and the cause was likely thought to be from plant trade pathways. The disease was first found on plants and in gardens, particularly rhododendron (*Ponticum P. Ramorum*) and was found first on Larch trees in South West of England and then found in South Wales the year later in the Afan Valley. The disease spread and has two different European lineages EU1 and EU2 with the EU1 strain present in Wales and being more common across Europe (King, Harris and Webber, 2015). The Pathogen leads to dieback of the stem, branch and foliage, travelling from the needles of larch trees into the branches and eventually infecting the live tissues under bark which has been found to cause lesions, cankers and necrosis (Daera, 2019). A number of biotic and abiotic factors including weather, proximity and sporulation rate can affect the rate of infection. Zoospores are the main route of spread which are spores that swim in droplets or water film but the disease can also be spread via Chlamydospores (resting spores) which enables the disease to survive through unfavourable conditions (Assembly, 2018). A study and climatic model were created by Cambridge University which found that the main reason affecting the rate of spread in Wales is the climate and through the use of this model areas of high risk were designated (Assembly, 2018). Zoospores are best suited to moist and windy air and so climate change is a worrying factor when regarding this disease. These Zoospores are produced in large quantities on the needles of larch and other foliar hosts which can be released up to 40m above ground level. This enables the disease to infect over large distances (Chadfield and Pautasso, 2012). There are now designated risk zones (shown below in fig 3) which were introduced in 2014 by the Welsh Government and stakeholders, after a review by scientists and their understanding of the disease.

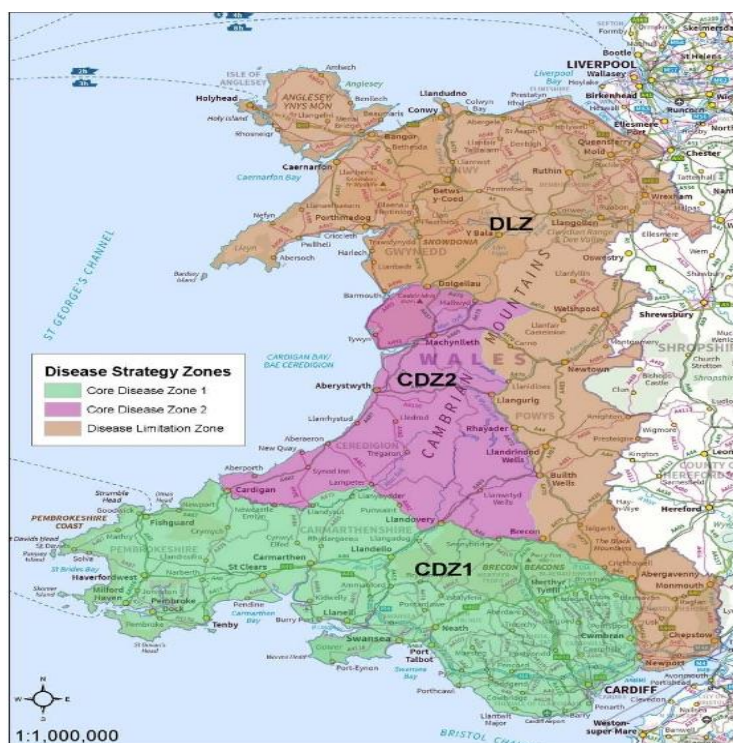
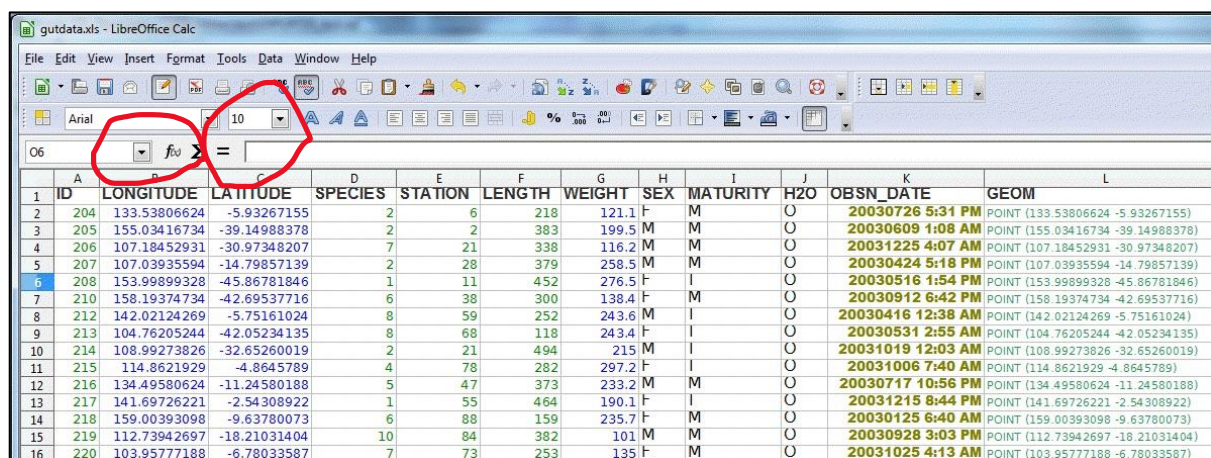


Figure 3 Map showing Control management and Core disease zones - NRW, 2019

3.0 Methodology

In order to create a GIS to show the spread of PR, a number of tools were utilized. Initially data sets containing geospatial data in the form of excel spreadsheets (table 1) were provided by the forestry commission Wales and the data was then directly opened in Map Info and added to a base map or Raster (fig 4) of the UK found by searching Digimaps online and converting the data download from a zip file to a MapInfo tab, shape or esri file. This provides a base layer or raster map to work from. The datasets used did not require much cleaning, but it can be essential to add dummy data if the datasets are incomplete, known as cleaning the datasets.

Spatial layers have been added to compare to the initial infected tree dataset (table 2) with different geospatial datasets found from a variety of sources such as The forestry Commission, Natural Resources Wales and added to the base map and data so patterns and concurrences could be analysed. Data queries using the SQL select function have been performed and added to the GIS to separate data into various specific sets such as different years of the diseases and locations of sightings, which have been colour coded by the range of years to look at the spread annually between 2010 and 2014. The queried maps were also used to create thematic maps which enabled a different form of visualization and the ability to create a bar graph to show different rates of spread across the boundary areas from the vector boundary map used.



	A	B	C	D	E	F	G	H	I	J	K	L
1	ID	LONGITUDE	LATITUDE	SPECIES	STATION	LENGTH	WEIGHT	SEX	MATURITY	H2O	OBSN_DATE	GEOM
2	204	133.53806624	-5.93267155	2	6	218	121.1	F	M	U	20030726 5:31 PM	POINT (133.53806624 -5.93267155)
3	205	155.03416734	-39.14988378	2	2	383	199.5	M	M	U	20030609 1:08 AM	POINT (155.03416734 -39.14988378)
4	206	107.18452931	-30.97348207	7	21	338	116.2	M	M	U	20031225 4:07 AM	POINT (107.18452931 -30.97348207)
5	207	107.03935594	-14.79857139	2	28	379	258.5	M	M	U	20030424 5:18 PM	POINT (107.03935594 -14.79857139)
6	208	153.99899328	-45.86781846	1	11	452	276.5	F	I	U	20030516 1:54 PM	POINT (153.99899328 -45.86781846)
7	210	158.19374734	-42.69537716	6	38	300	138.4	F	M	U	20030912 6:42 PM	POINT (158.19374734 -42.69537716)
8	212	142.02124269	-5.75161024	8	59	252	243.6	M	I	U	20030416 12:38 AM	POINT (142.02124269 -5.75161024)
9	213	104.76205244	-42.05234135	8	68	118	243.4	F	I	U	20030531 2:55 AM	POINT (104.76205244 -42.05234135)
10	214	108.99273826	-32.65260019	2	21	494	215	M	I	U	20031019 12:03 AM	POINT (108.99273826 -32.65260019)
11	215	114.8621929	-4.8645789	4	78	282	297.2	F	I	U	20031006 7:40 AM	POINT (114.8621929 -4.8645789)
12	216	134.49580624	-11.24580188	5	47	373	233.2	M	M	U	20030717 10:56 PM	POINT (134.49580624 -11.24580188)
13	217	141.69726221	-2.54308922	1	55	464	190.1	F	I	U	20031215 8:44 PM	POINT (141.69726221 -2.54308922)
14	218	159.00393098	-9.63780073	6	88	159	235.7	F	M	U	20030125 6:40 AM	POINT (159.00393098 -9.63780073)
15	219	112.73942697	-18.21031404	10	84	382	101	M	M	U	20030928 3:03 PM	POINT (112.73942697 -18.21031404)
16	220	103.95777188	-6.78033587	7	73	253	135	F	M	U	20031025 4:13 AM	POINT (103.95777188 -6.78033587)

Table 1 Table showing use of coordinate data on Excel - Boyd, 2016



Figure 4 Map or Raster image - Digimaps 2019

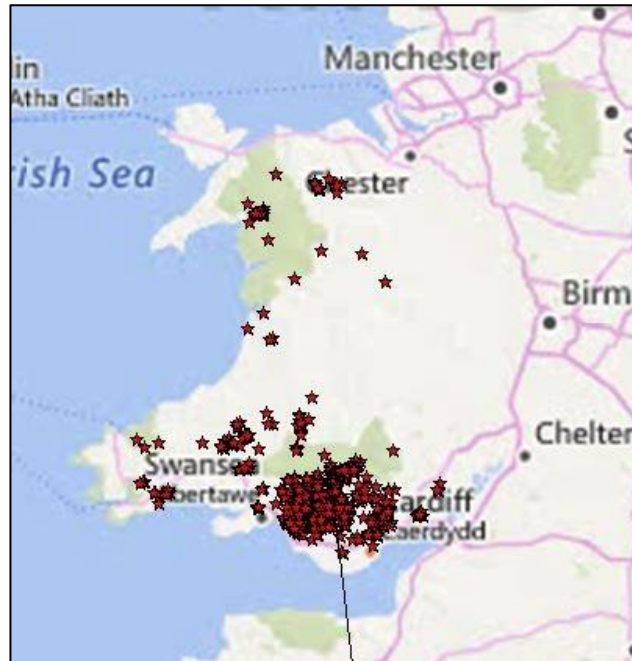


Figure 5 Map showing Infected data on Map - Mapinfo, 2020

Table 2 Table showing infected tree data, Mapinfo, 2020

STATUS_OF_SITE	FCW_Privat	Assess_Year_Data	X_coordinate	Y_coordinate	Grid_Reference	
Confirmed infected	Private	2011-2012	281,024.45	193,474.86	SS8102493474	
Confirmed infected	FCW	2013-2014	288,681.23	197,763.75	SS8868197763	
Confirmed infected	Private	2013-2014	322,285.97	195,943.36	ST2228595943	
Confirmed infected	FCW	2013-2014	278,999.69	190,148.33	SS7899990148	
Confirmed infected	FCW	2013-2014	284,969.7	201,581.34	SN8496901581	
Confirmed infected	FCW	2012-2013	303,721.43	204,250.03	SO0372104250	
Confirmed infected	FCW	2013-2014	281,281.55	205,230.57	SN8128105230	
Confirmed infected	FCW	2013-2014	280,938.19	204,837.84	SN8093804837	
Confirmed infected	FCW	2013-2014	300,960.92	209,854.01	SO0096009854	
Confirmed infected	FCW	2013-2014	279,388.94	190,152.86	SS7938890152	
Confirmed infected	FCW	2013-2014	298,860.94	189,881.78	SS9886089881	
Confirmed infected	FCW	2013-2014	299,474.03	189,901.7	SS9947489901	
Confirmed infected	FCW	2013-2014	322,365.9	197,560.2	ST2236597560	
Confirmed infected	FCW	2013-2014	283,901.75	202,598.33	SN8390102598	
Confirmed infected	FCW	2013-2014	274,339.79	207,950.87	SN7433907950	
Confirmed infected	FCW	2013-2014	282,640.8	204,868.6	SN8264004868	
Confirmed infected	FCW	2013-2014	282,765.51	204,930.11	SN8276504930	
Confirmed infected	FCW	2013-2014	321,573.23	192,575.4	ST2157392575	
Confirmed infected	Private	2011-2012	276,884.61	212,543.18	SN7688412543	
Confirmed infected	FCW	2010-2011	281,275.27	192,936.05	SS8127592936	
Confirmed infected	FCW	2011-2012	278,843.35	191,229.32	SS7884391229	
Confirmed infected	FCW	2010-2011	287,872.48	192,361.59	SS8787292361	
Confirmed infected	FCW	2010-2011	287,647.31	192,717.2	SS8764792717	
Confirmed infected	FCW	2010-2011	283,265.87	192,327.43	SS8326592327	

Table 3 Mao showing infected tree data query 2010-2011 range - mapinfo, 2020

STATUS_OF_SITE	FCW_Privat	Assess_Year_Data	X_coordinate	Y_coordinate	Grid_Reference
Confirmed infected	FCW	2010-2011	281,275.27	192,936.05	SS8127592936
Confirmed infected	FCW	2010-2011	287,872.48	192,361.59	SS8787292361
Confirmed infected	FCW	2010-2011	287,647.31	192,717.2	SS8764792717
Confirmed infected	FCW	2010-2011	283,265.87	192,327.43	SS8326592327
Confirmed infected	FCW	2010-2011	282,739.49	192,784.55	SS8273992784
Confirmed infected	FCW	2010-2011	282,363.8	194,474.59	SS8236394474
Confirmed infected	FCW	2010-2011	287,273.99	193,987.61	SS8727393987
Confirmed infected	FCW	2010-2011	276,632.27	191,616.05	SS7663291616
Confirmed infected	FCW	2010-2011	276,256.93	191,863.83	SS7625691863
Confirmed infected	FCW	2010-2011	281,486.17	191,342.62	SS8148691342
Confirmed infected	Private	2010-2011	293,889.44	356,093.79	SH9388956093
Confirmed infected	FCW	2010-2011	281,960.14	194,978.59	SS8196094978
Confirmed infected	FCW	2010-2011	282,084.06	194,936.91	SS8208494936
Confirmed infected	FCW	2010-2011	282,109.86	194,876.95	SS8210994876
Confirmed infected	FCW	2010-2011	281,942.06	194,688.55	SS8194294688
Confirmed infected	FCW	2010-2011	290,214.91	191,062.24	SS9021491062
Confirmed infected	FCW	2010-2011	290,107.16	191,567.99	SS9010791567
Confirmed infected	FCW	2010-2011	281,308.06	197,221.43	SS8130897221
Confirmed infected	FCW	2010-2011	293,794.51	354,934.56	SH9379454934
Confirmed infected	FCW	2010-2011	294,081.32	355,092.61	SH9408155092
Confirmed infected	FCW	2010-2011	294,333.16	355,476.95	SH9433355476
Confirmed infected	Private	2010-2011	294,275.12	355,947.89	SH9427555947
Confirmed infected	FCW	2010-2011	281,007.53	195,489.78	SS8100795489
Confirmed infected	FCW	2010-2011	281,263.53	192,503.59	SS8126392503

4.0 Results and Analysis

The variables are shown as overlays to the base raster map and boundaries maps found on Digi maps. The spatial layers will be discussed above each screenshot to provide analysis of the results found when building this case study.

The Analytical visualisation point for the study began by querying and drilling down on specific data distribution in order to get a look at the spread of the disease by year. The data was separated into years ranging from 2010-2011 (fig 6), 2012-2013 (fig 7) and 2014 (fig 8) and it became clear when visualising the data that the spread was increasing each year from 2010-2014, which would seem concurrent with the movement of air water droplets and mist etc which is largely based on wind strength and climatic conditions as previously mentioned. In the first screenshot you can see the spread is quite contained within an area of the Afan Valley but over the 2 following screenshots that the spread is increasing. The thematic maps (fig 10-13) show the SQL queries by year and the spread per boundary area by counts and enable a different type of visualisation of the data. The bar chart below acts as an analysis tool by showing different spread amounts per boundary area (fig 14).

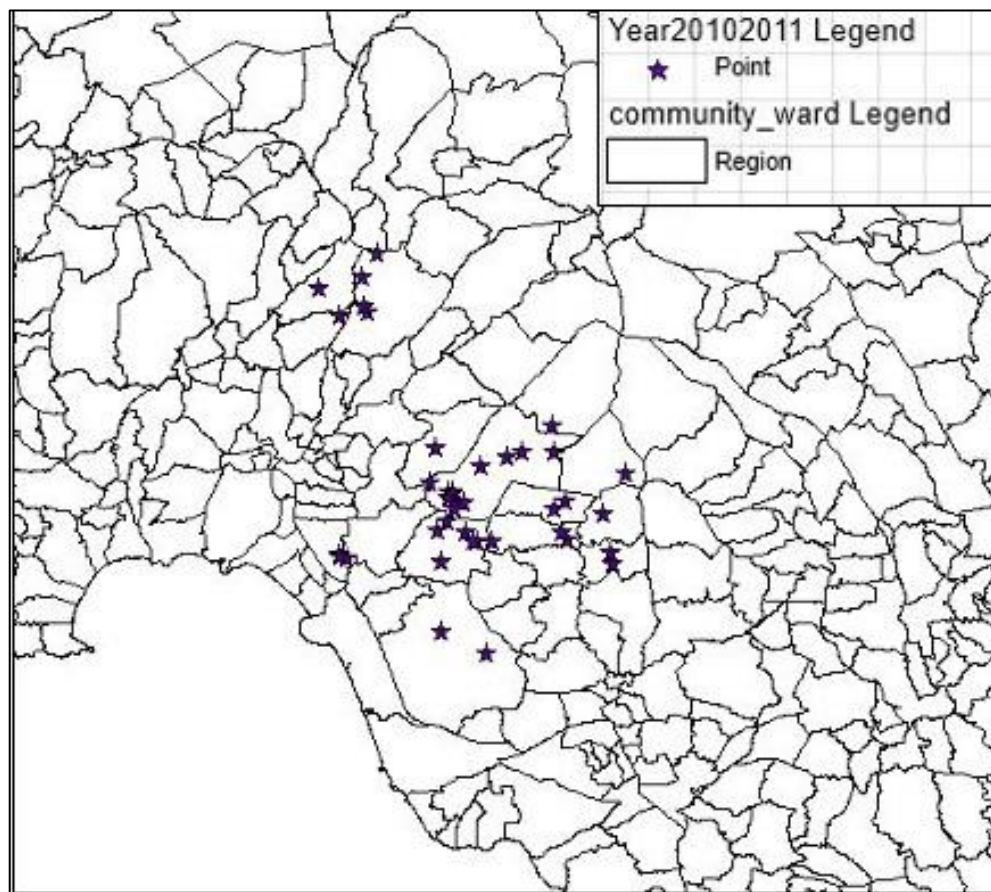


Figure 6 Map showing SQL query 1 2010-2011 data

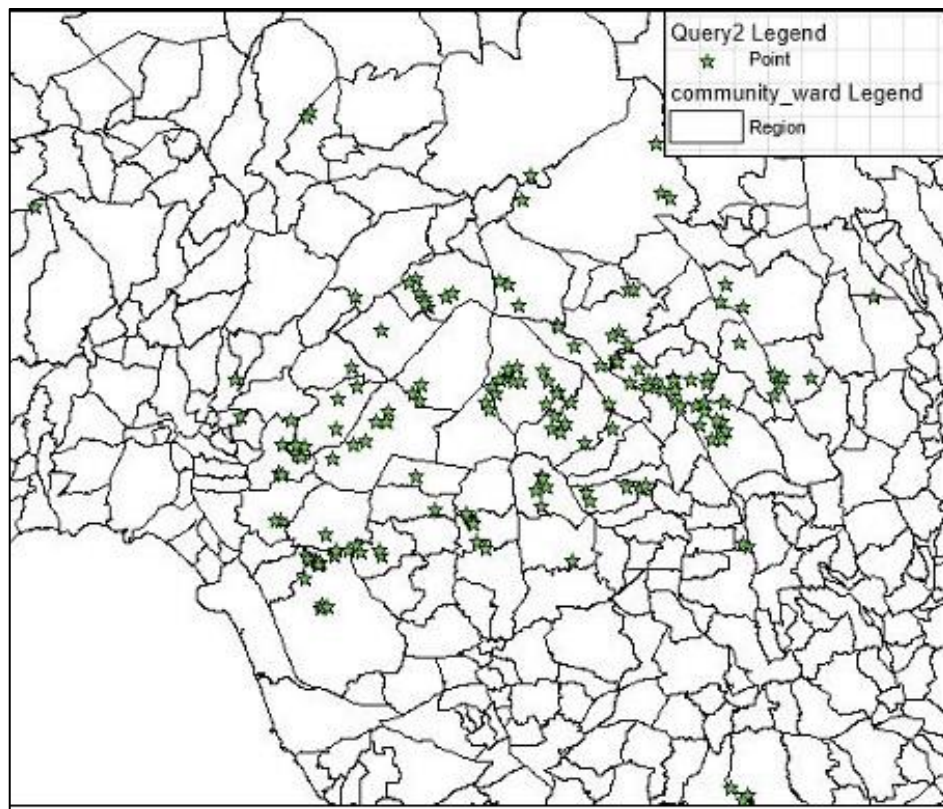


Figure 7 Map showing SQL query 1 2012-2013 data

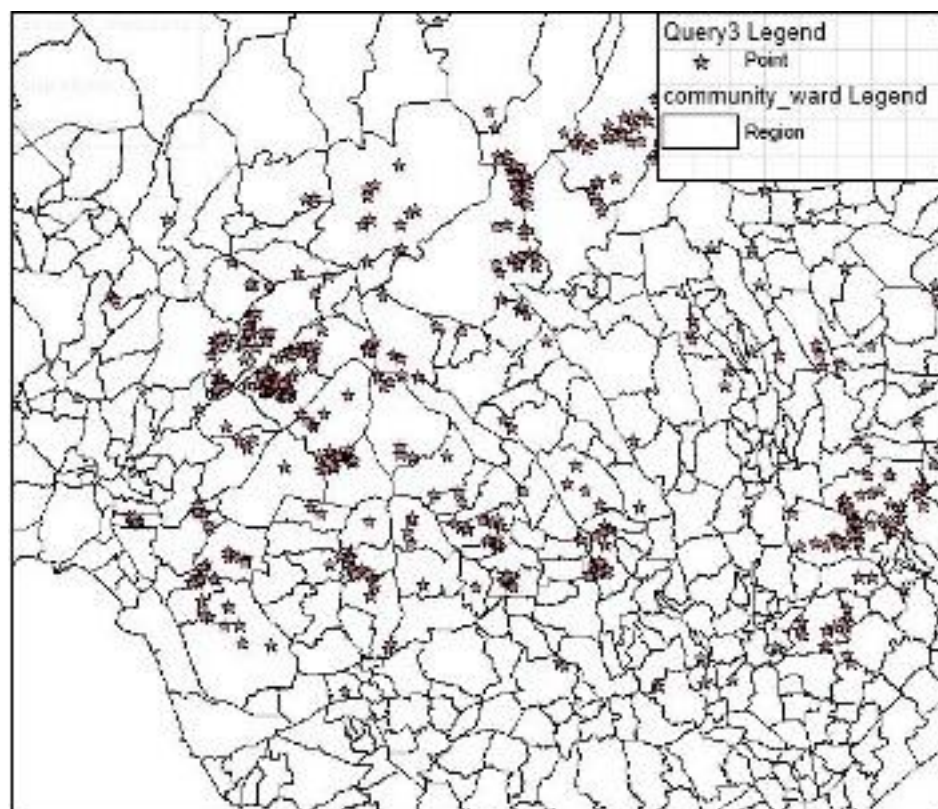


Figure 8 Map showing SQL query 2014 data

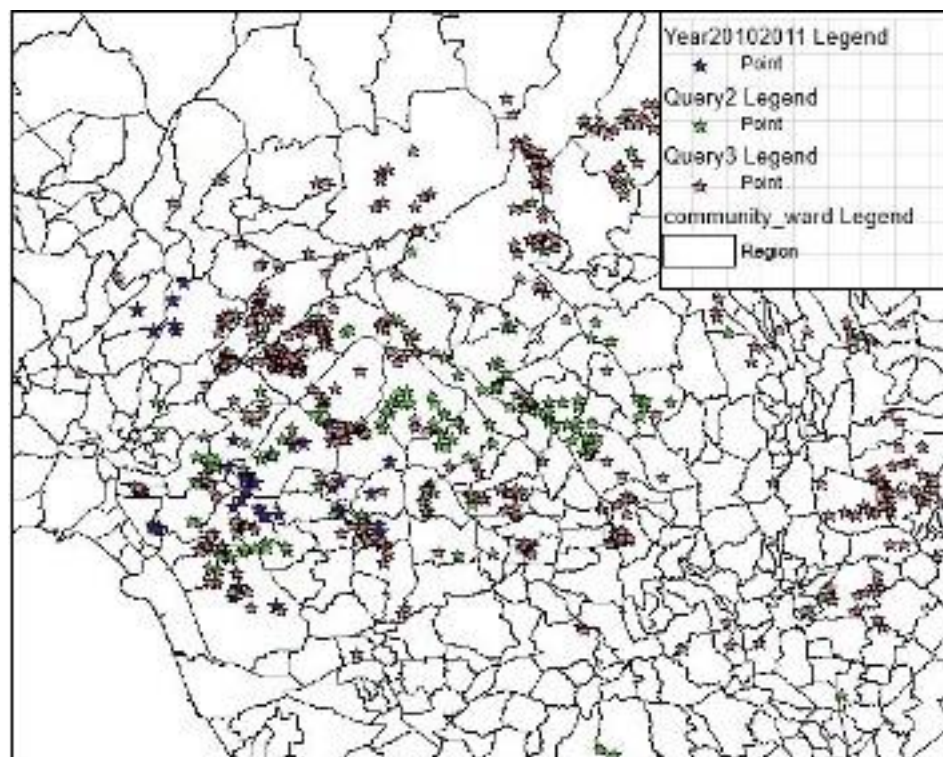


Figure 9 Map showing all Year data

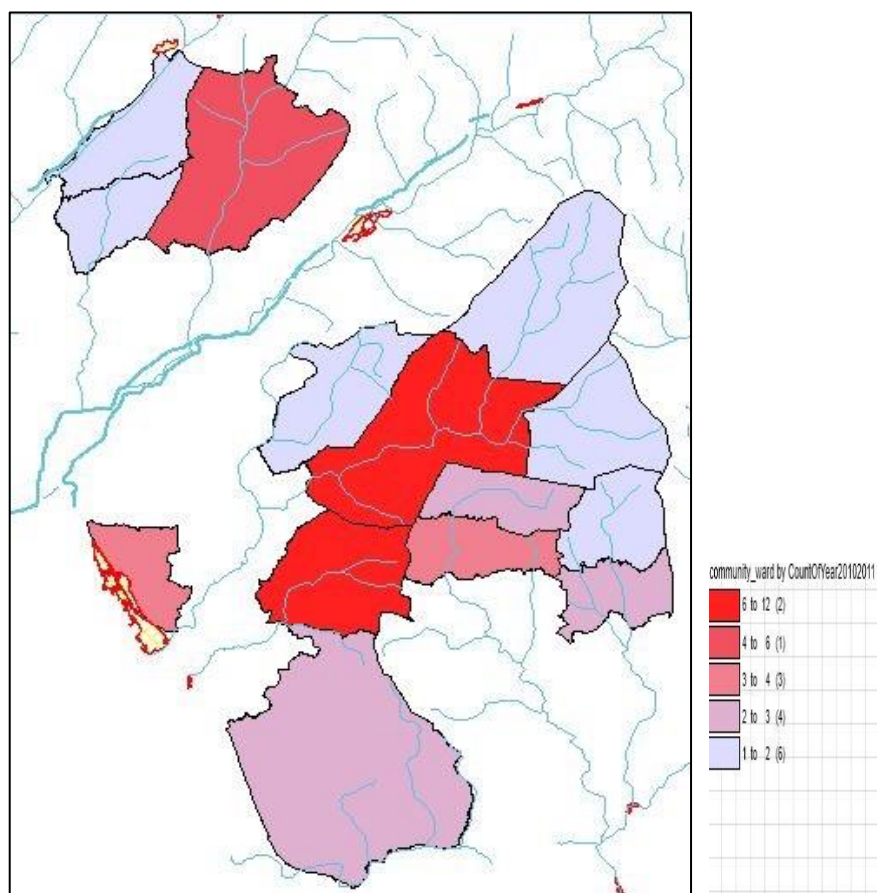


Figure 10 Thematic Map showing spread by year 2010-2011

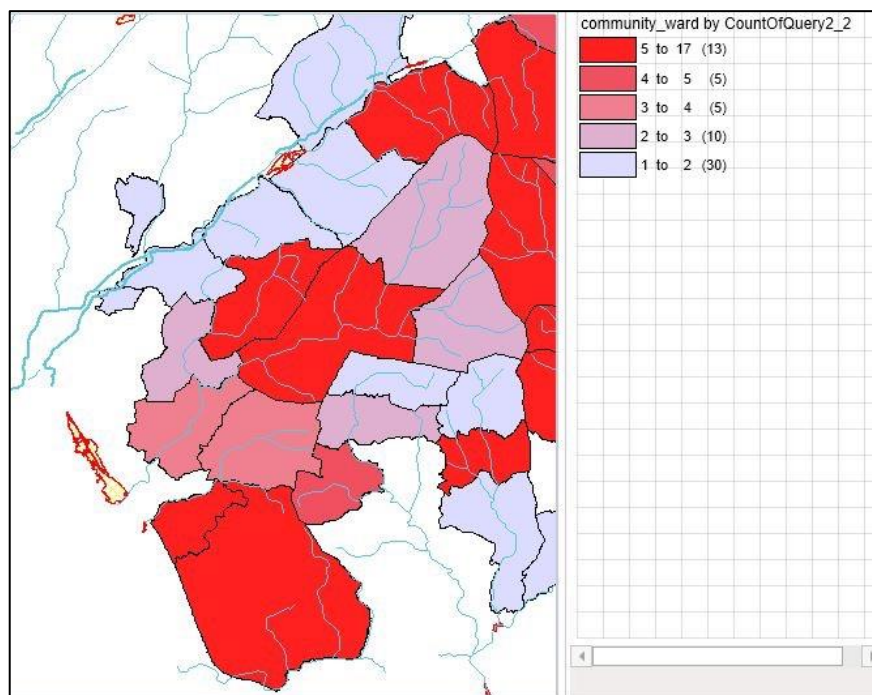


Figure 11 Thematic Map showing spread by year 2012-2013

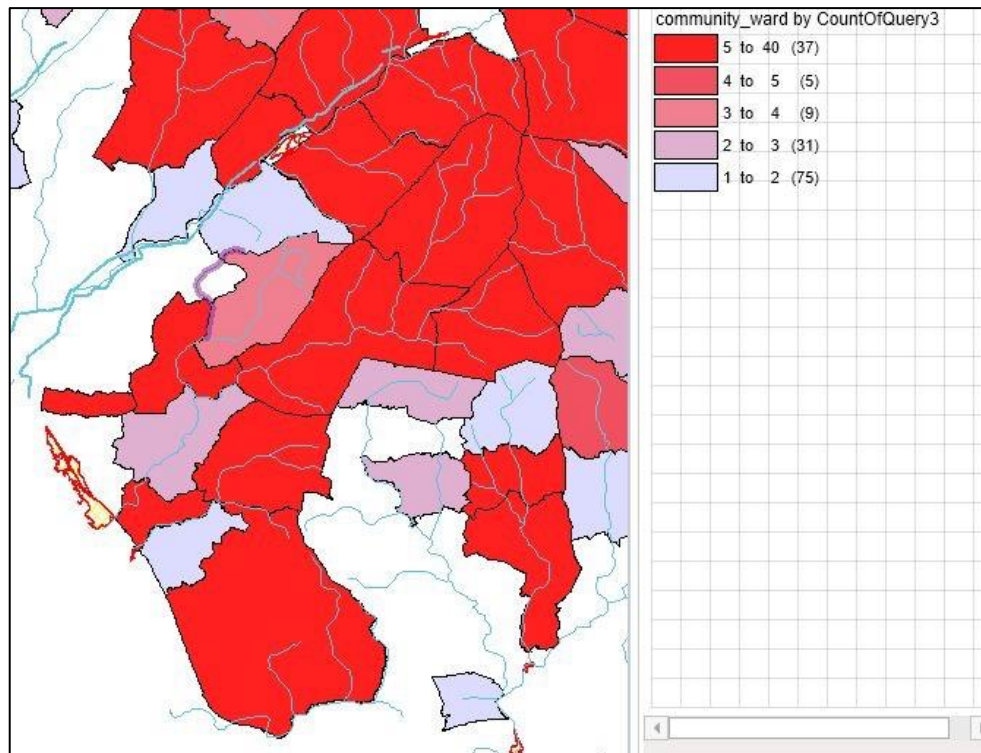


Figure 12 Thematic Map showing spread by year 2014

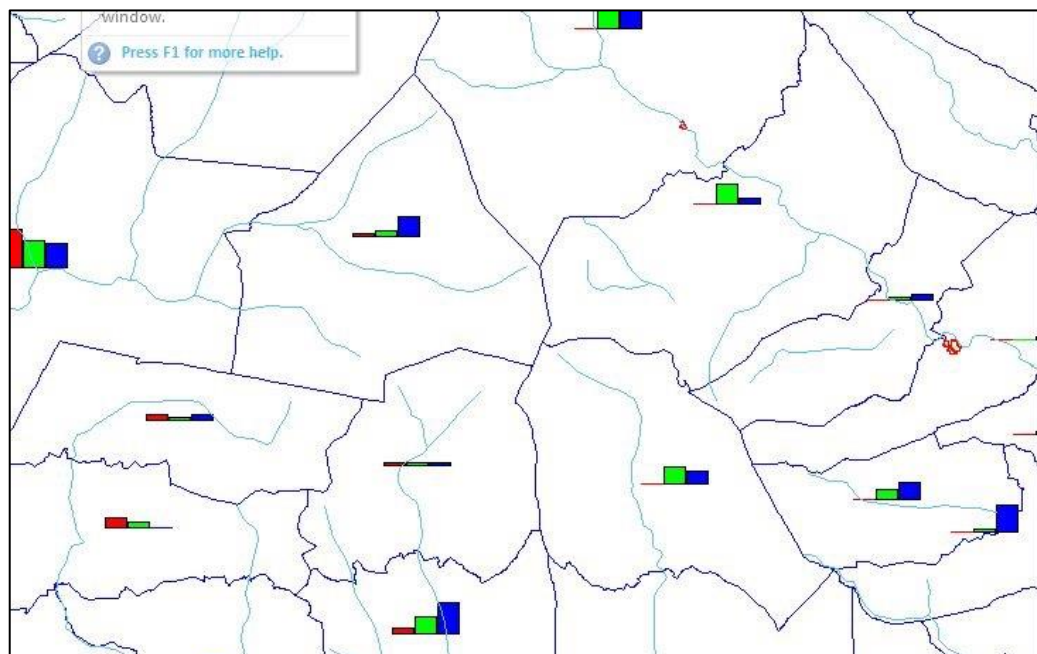


Figure 13 Bar chart map from thematic map of year by year data

In order to test hypothesis 2 a selection of tourist and recreational hotspot overlays, along with A roads were added as variables to understand whether human footfall and travel could be affecting the spread of the disease. In the first screenshot (fig 15)the overlay of tourist hotspots shows some correlation to the clustering, but with the possibility that tourist hotspots could well be locations with trees which are often recreational spots, the layer proved inconclusive.

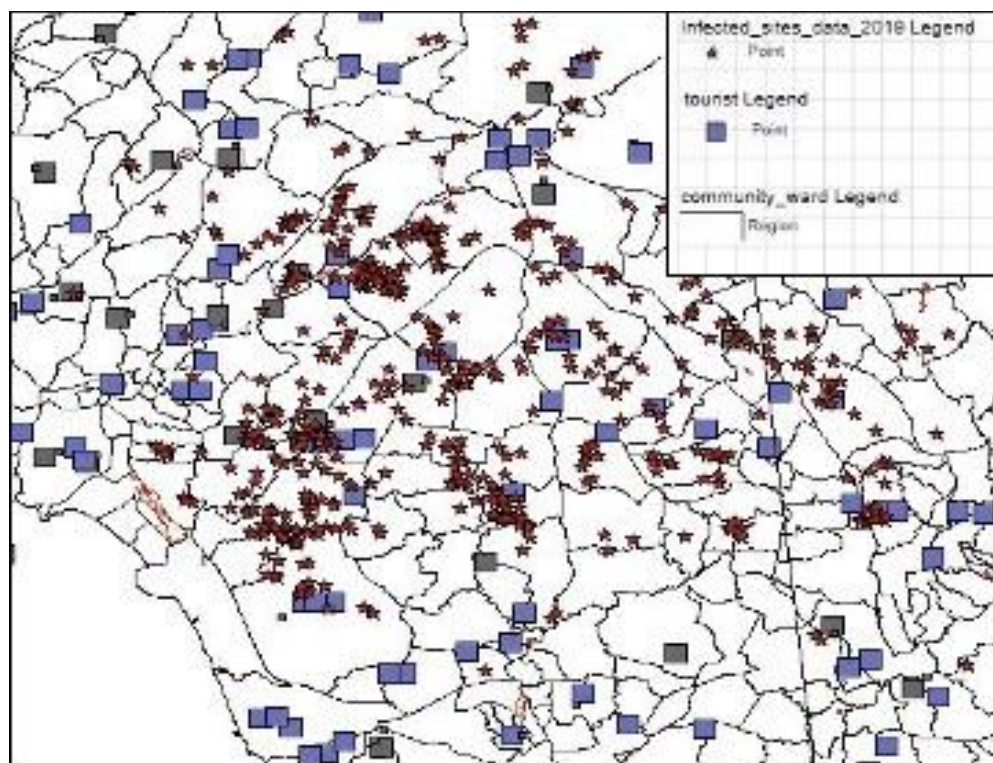


Figure 14 Map showing Tourist recreational hotspots and infected tree data

Again whilst adding Country parks (fig 16) to look further into whether this could be due to typical locations of human footfall being visits to forests for recreation, the country parks overlay did not add any further conclusions or correlations.

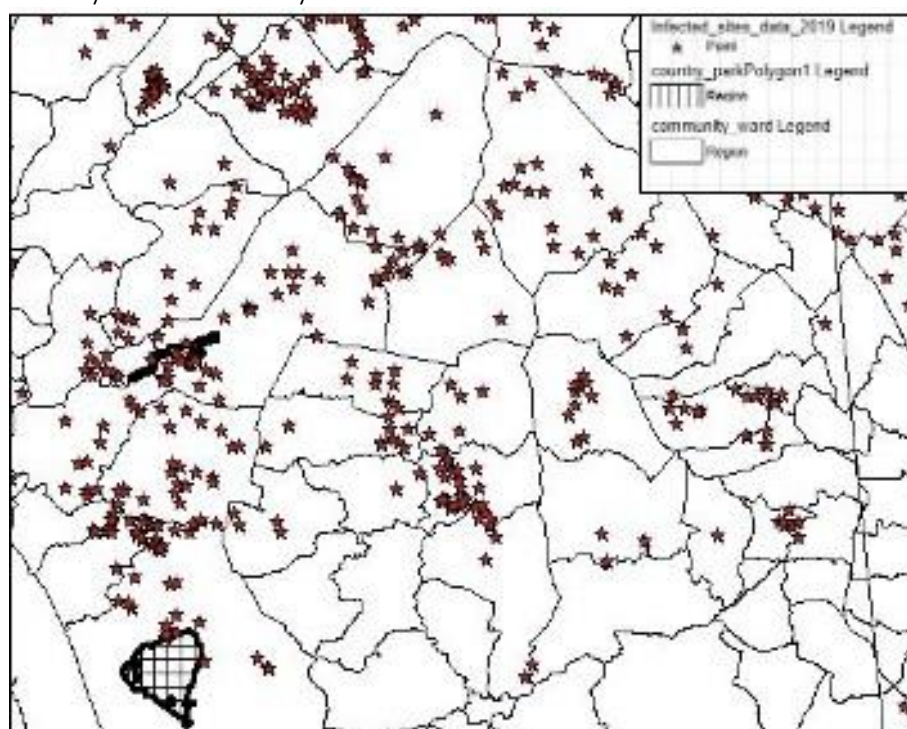


Figure 15 Map showing country parks and infected tree data

In the below screenshot (fig17) the variable of A roads in Wales was added, which when combined with the infected tree data provided by the Forestry commission, found little correlation, there appear to be some clusters along roadsides but nothing conclusive to support the hypothesis that the movement of people may contribute to the spread.

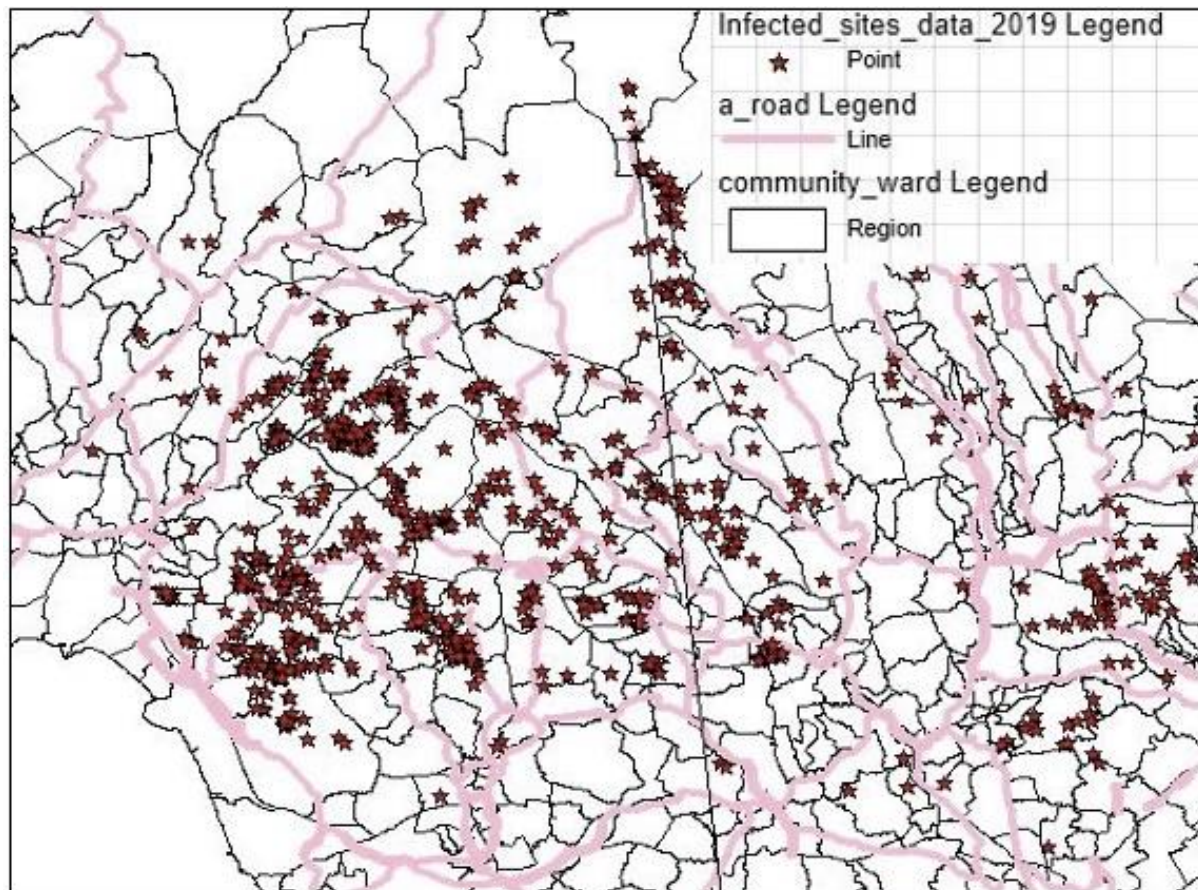


Figure 16 Map showing A roads and infected tree data

In the following screenshot of the GIS, data was added from geographical locations of rivers across Wales and revealed some correlations to the spread. You can see (fig 18) that on a number of drilled in views, the disease appears to follow the waterways, though there are other potential variables which could make this inconclusive and so additional dataset provision and analysis appears necessary to support hypothesis 1.

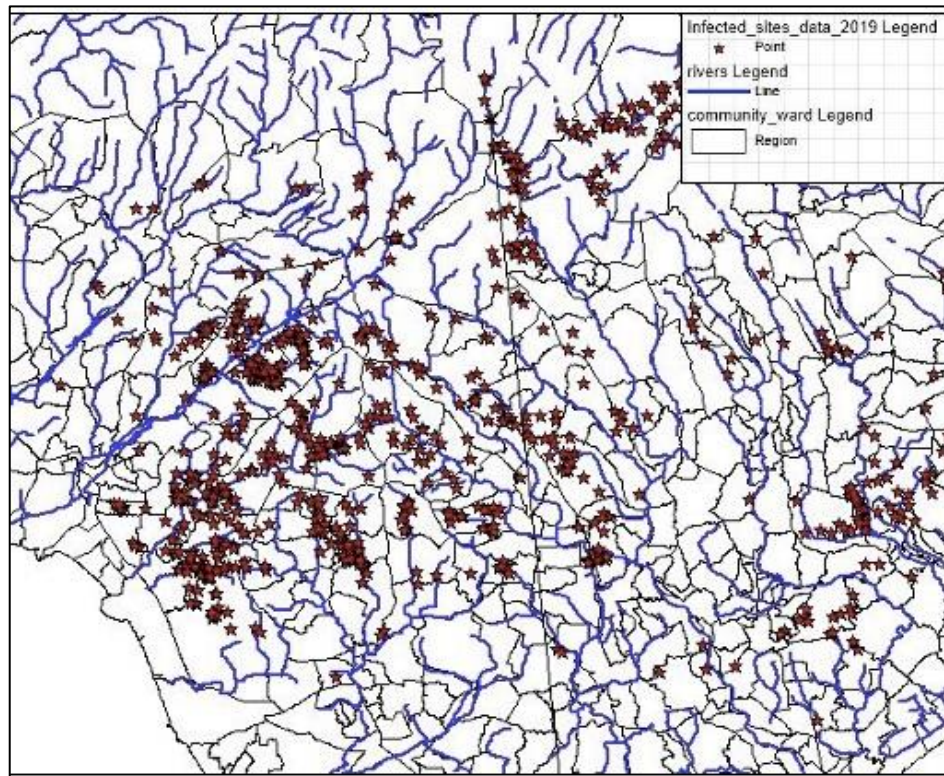


Figure 17 Map showing rivers and infected tree data

In the screenshot below (fig 19) A roads and rivers were combined to look for correlation and some clusters found alongside rivers and roads but again not conclusive evidence.

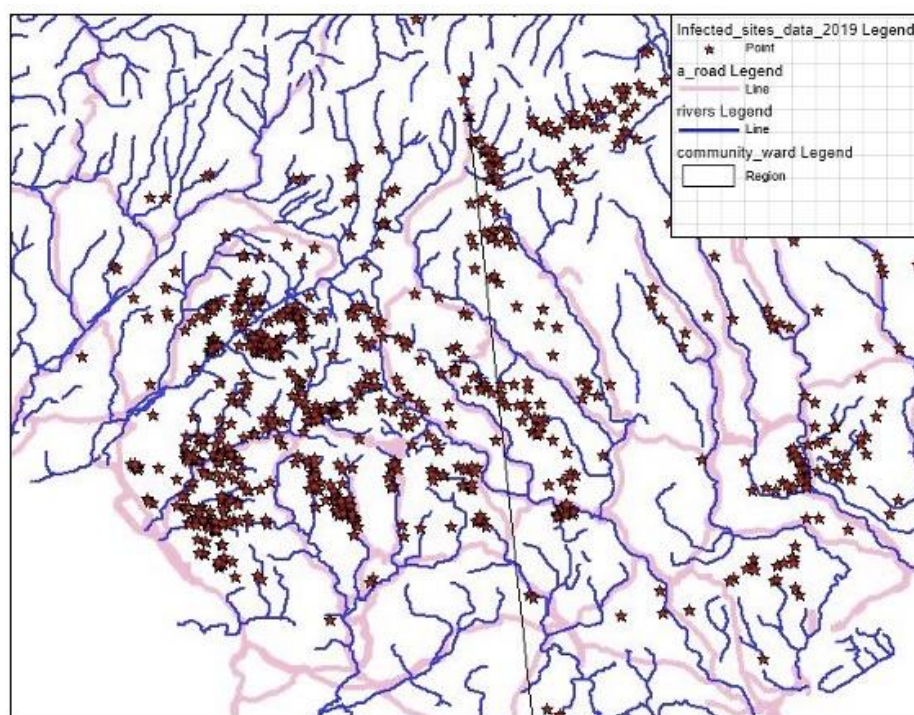


Figure 18 Map showing A roads, rivers and infected tree data

For the following query, geospatial data containing a full woodland inventory (fig 20 - 21) from the LLE portal on NRW's website was overlaid and offered a variety of categories which could be drilled down and when selecting types and adding the overlay to the infected tree data, there was some correlation between infected sights and felled and young trees, this could also be due to the data provided by forestry commission data being restricted and only showing spread between 2010-2014 2014, and as this overlay is possibly more up to date this could mean that this is just locations already managed over more recent years than the data provides. An additional comparison was made by adding a river spatial map, but no further concurrences were found through this method.

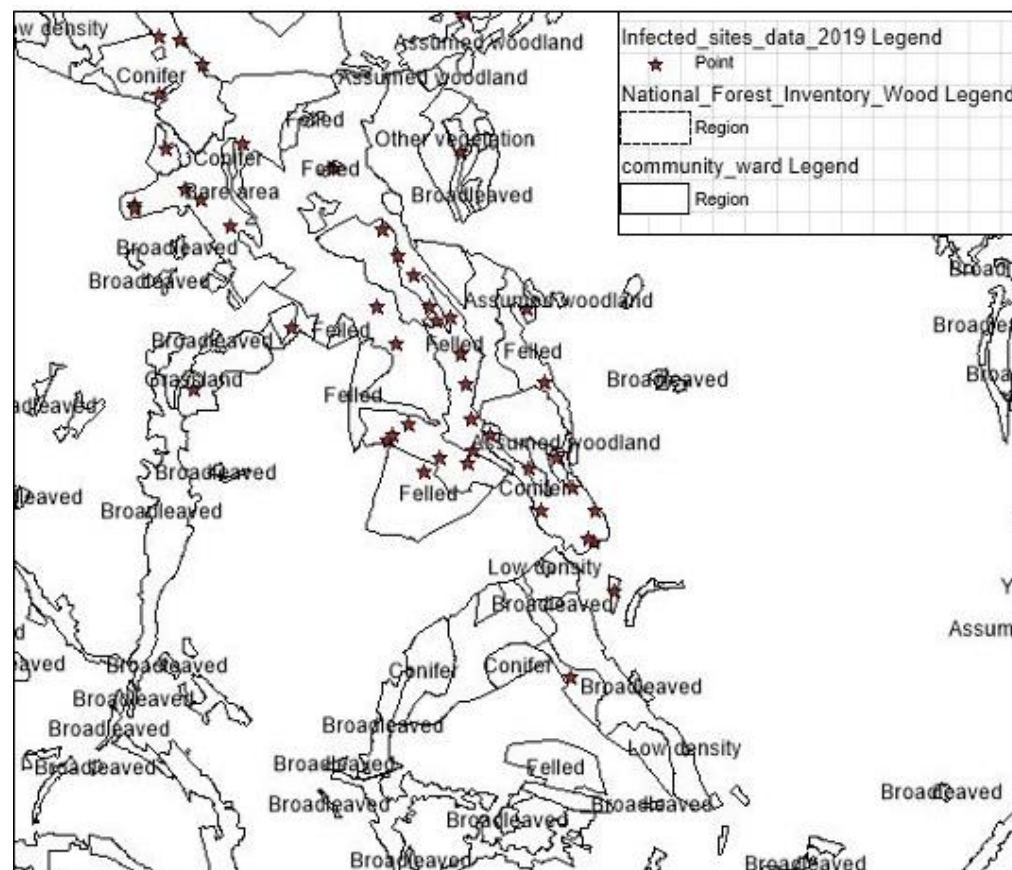


Figure 19 Map showing Woodland inventory and infected tree data and zoomed

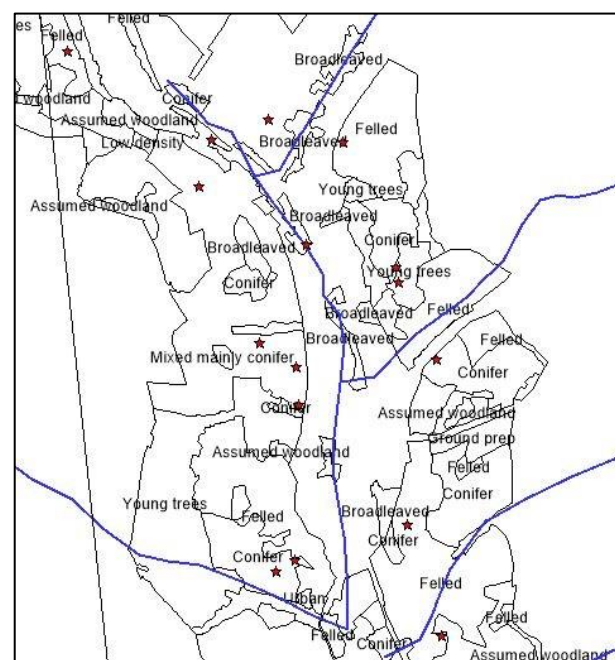


Figure 20 Map showing Woodland inventory , river and infected tree data close up

The screenshot below (fig 22)provided some strong providing evidence to the hypothesis 1 and literature found that the pathogen PR is spread via water. The following datasets, provided by Natural Resources Wales from the LLE portal site and layers including Woodland inventory, Riparin Woodland and Attenuation spots along with surface water flooding were added and analysed. Through the addition of these layers some firm correlations were concluded. The datasets of Riparian woodland, waterway locations and the infected tree dataset highlighted clear clusters on the map and when drilling down onto specific areas as shown below in (fig 23) there is a clear curve to the spread along the rivers and riparian woodland. Adding the attenuation maps (fig 24) and surface water spread(fig 25) layers did not provide any further evidence.

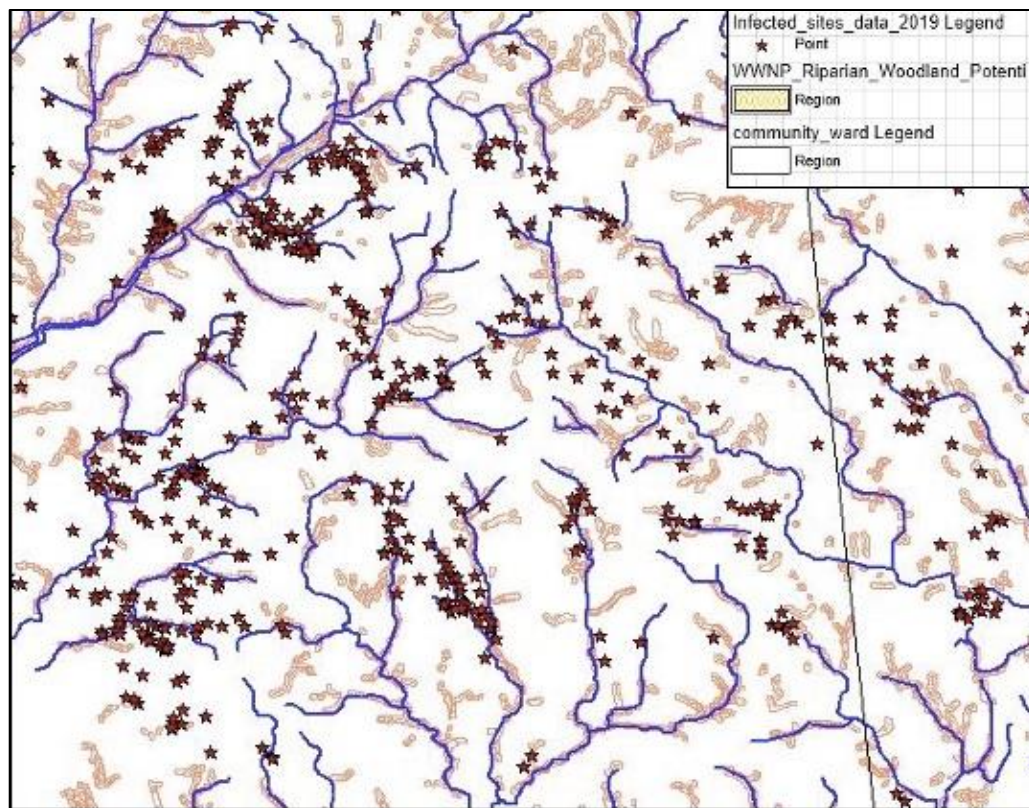


Figure 21 Map showing Riparian woodland, rivers and infected tree data

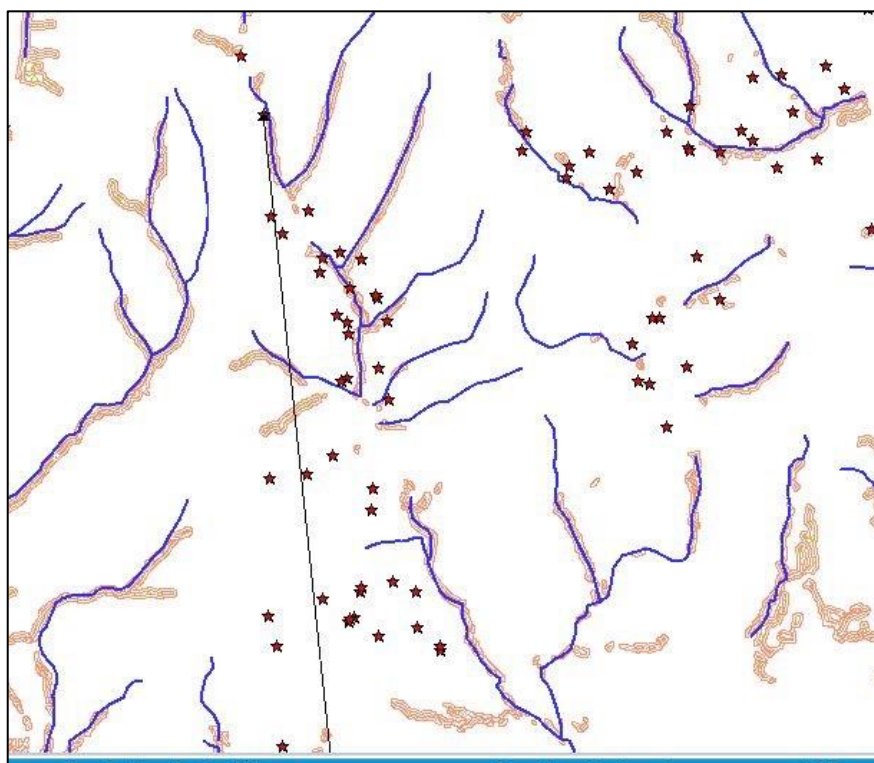


Figure 22 Map showing Riparian woodland, rivers and infected tree data close up

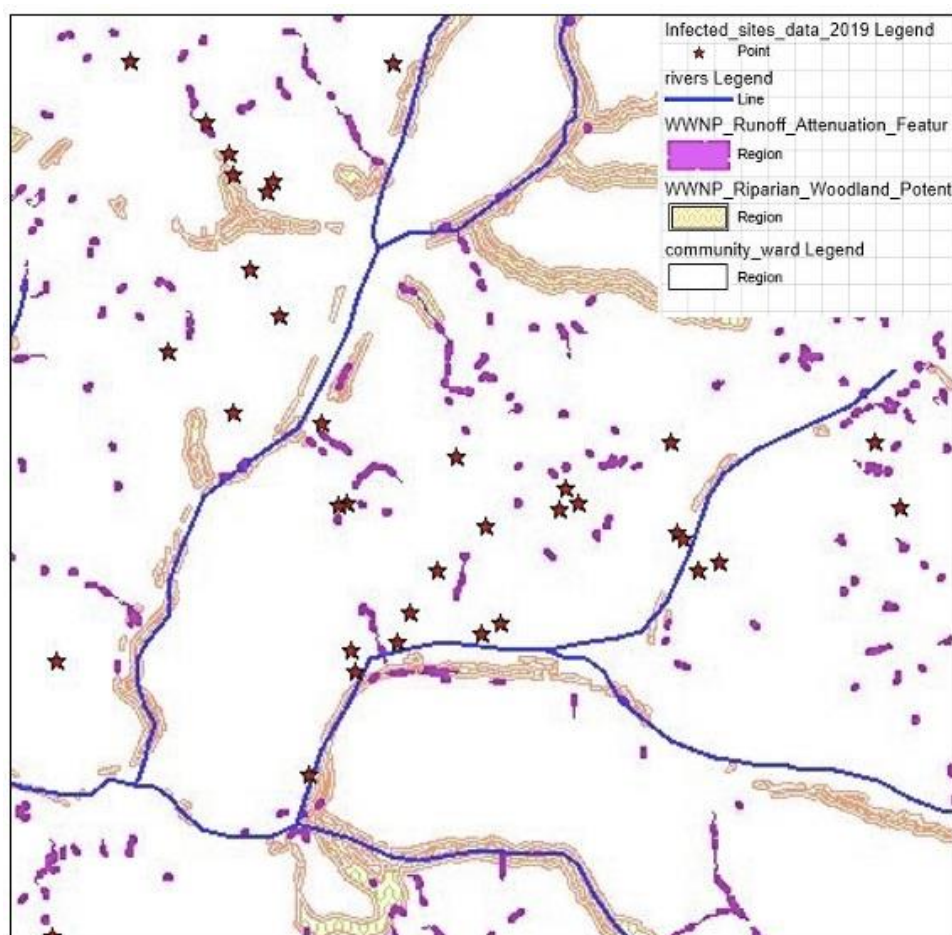


Figure 23 Map showing Riparian woodland, rivers, attenuation/runoff and infected tree data

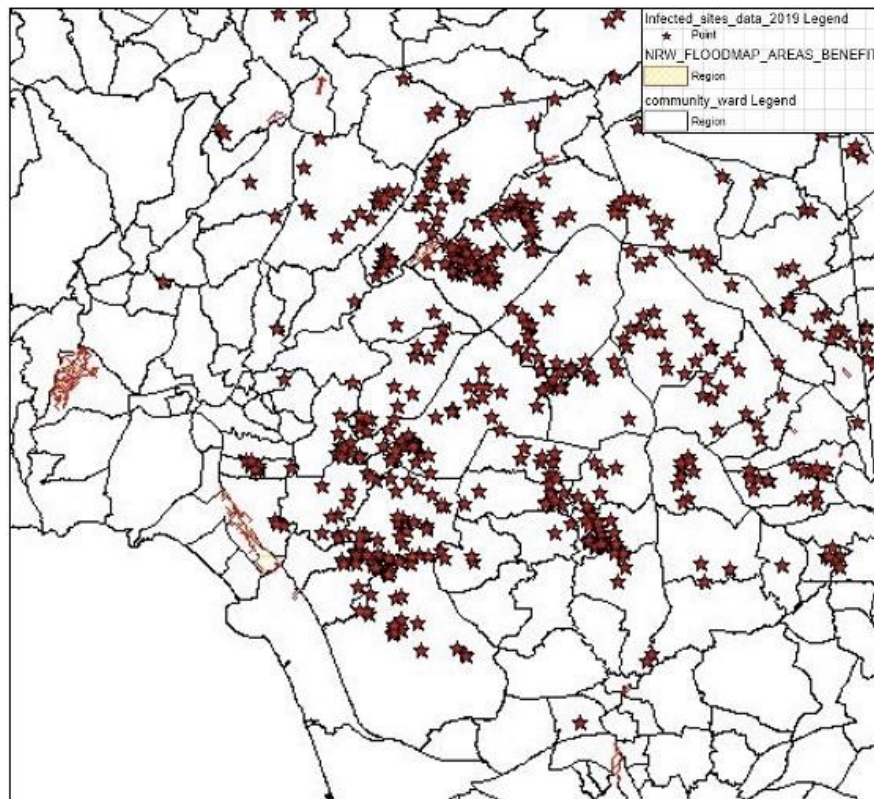


Figure 24 Map showing surface water runoff and infected tree data

5.0 Conclusion

In conclusion the use of Geographical information systems for use as a modelling tool in environmental management and analysis provided a fast visualisation of the data collected and indeed helped to show patterns that enable conclusions through statistical analysis of environmental issues. The spread of PR can clearly be linked to water and there was a clear pattern found when combining spatial datasets. When regarding the spread of PR through human footfall, less conclusions were drawn, and further datasets would be recommended to analyse this further. A greater availability of spatial data would help to form clearer conclusions and was quite difficult to obtain, the movement of timber imports would be recommended but datasets including georeferencing were not located on this occasion. Provision of this data could provide further insight into whether the spread can be attributed to footfall and human activity. The software MapInfo was somewhat difficult to run on a Mac through a virtual box and slowed down processing time which could be seen as a downside, the processing of each layer was slow and cumbersome but the results worth the wait.

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