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Chapters 6 to 7, Appendix and References

DEVELOPING ARTIFICIAL LIFE SIMULATIONS OF VEGETATION TO SUPPORT THE VIRTUAL RECONSTRUCTION OF ANCIENT LANDSCAPES

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Chapter 6

Growing Virtual Vegetation in Mesolithic Landscapes

6.1. Introduction

An Artificial Life-based vegetation model presented and verified in previous chapters is used here for reconstructing segments from the Shotton river valley. The approach addresses the limitations observed in the methodology of past predictive vegetation models by the inclusion of a temporal element necessary for synthesising the lifecycle of plants in the growth, reproduction, seed germination, and competition based on seasonal changes. Past experiments have demonstrated that characteristic rules extracted from knowledge and observations of vegetation lifecycle coupled with real botanical properties are able to synthesise vegetation dispersal patterns comparable to that of their natural counterpart. The simulation showed that the collective effects of interaction between the Artificial Life plant entities, both providing nutrients and competing for resources emerge as patterns on landscapes. Furthermore, environmental conditions as ecological signals benefit or threaten the life of each plant and its offspring. The changing pattern witnessed in the studies did not issue from an individual alife entity; instead, they emerge by the local interaction of the entities that collectively form patterns in the virtual terrains, much like those found in natural landscapes. Such self-organisation in clothing a terrain with the diversity of flora supports the attempts of this research at studying the potentials of Artificial Life techniques for solving ancient landscape mystery such as the Shotton River Valley.

In this chapter, a compressed simulation concept is introduced for optimising the speed and efficiency of the simulation and a comparison with normal speed simulation is made for identifying feasibility with the optimised approach for application in archaeological reconstructions. Later, the optimised approach is applied to landscape segments extracted from the Shotton river valley. Finally, the characteristics of growth and distribution of Mesolithic trees and its undergrowth are reconstructed in a games engine simulation platform, concluding the experiential aspect of the Virtual Heritage research project for archaeological interpretations.

6.2. A Mesolithic Scenario

Two scenarios representing a Mesolithic landscape beginning in the year 9,200bp are reconstructed for simulation. The model includes all environmental factors covered in the preceding sections. The purpose of the study is to demonstrate the feasibility of using the model presented in Chapter 4 and experimented in the previous chapter for reconstructing ancient landscapes in the Mesolithic age. A landscape 150m² is constructed hosting an ecosystem of six main woodland species – Pine, Hazel, Willow, Oak, Birch, Elm. Their genetic structures described in XML are listed in Appendix B. Ecosystem parameters and ecological signals uses those defined in section 4.4. The simulations demonstrate the overall impact on existing vegetation from migration of new species and temperature variations in a 250 year (Figure 123) and 318 year (Figure 125) period. Two scenarios are required for comparing the differences in impact of migrating species and temperature variation on existing ones. The simulations are preceded by an investigation into the feasibility of further optimisation by comparing the results between the normal monthly simulation used throughout this chapter and an optimised version using only a four-seasonal yearly simulation cycle.

The migration and temperature variation tables for the first scenario can be seen in Table 31 and Table 32. Of the number of plants migrating in its respective years, not all will survive. The Hazel arrives at year 100, the Elm species arrives 30 years later followed by the Oak species at year 160. Temperature change is set to increase by +1.7ºC over 100 years for three consecutive phases before settling at a constant rate. In total over 300 years, the temperature would have increased by +5.1ºC throughout the landscape.

Table 31. Migration table for the first scenario

Year	Species	Number of Plants	Age of Plants
100	Hazel	40	10
130	Elm	40	10
160	Oak	40	10

Table 32. Temperature variation for the first scenario

Temperature Change	Over *n* Year(s)
+1.7	n = 100
+1.7	n = 100
+1.7	n = 100

The migration and temperature variation tables for the second scenario can be seen in Table 33 and Table 34. In this scenario, the Elm and Oak species arrives much earlier than Hazel. Temperature change is set to increase by +1.7ºC over 50 years for four consecutive phases before settling at a constant rate. In total over 200 years, the temperature would have increased by +6.8ºC throughout the landscape.

Table 33. Migration table for the second scenario

Year	Species	Number of Plants	Age of Plants
20	Elm	40	10
30	Oak	40	10
200	Hazel	40	10

Table 34. Temperature variation for the second scenario

Temperature Change	Over *n* Year(s)
+1.7	n = 50
+1.7	n = 50
+1.7	n = 50
+1.7	n = 50

6.2.1. Optimisation: Four-Seasonal Cycle

The simulation scenarios throughout the chapter use a twelve-month cycle for each simulation year. In the simulation, increase in vegetation population causes a proportional decrease in simulation speed. This is expected and is due to the fact that each vegetation entity contains large amounts of variables required to synthesise realistic plant lifecycles. This, together with species interaction between large numbers of plants, greatly increases the time required to complete a simulation step. Therefore, it is realised early in this research that optimisation techniques are required to counter the effects of large population growth of vegetation on limited computing resources. The segmentation algorithm introduced in Chapter 4 was applied to counter this effect throughout the experiments. The application of the segmentation algorithm has demonstrated significant increase in performance in all simulations. However, the exponential population growth of reproducing plants will eventually impede the speed of the simulation no matter how efficient the optimisation techniques are. This is especially true in large terrain simulations. Even though the segmentation algorithm will eventually stabilise the simulation speed as existing vegetations prevent further growth by occupying all available spaces on the landscape, there is the need for further optimisation or ways of reducing the simulation time.

Experimental observations throughout this chapter have established a basic fact. It is discovered that, regardless of the initial conditions, the ecosystem will eventually reach a “climax community” – a stable condition where each species occupies its ecological niches by forming ecotones and ecoclines. With this as a basis, reducing the simulation steps required to complete the full course of time should produce relatively similar results in a climax community. This is with the assumption that environmental conditions remained the same in the compressed simulation.

The simulation settings from the previous section (5.4) were used in a compressed version by reducing the annual simulation cycle from a monthly average of environmental conditions to just four seasonal cycles. Furthermore, the migration table was compressed so that the Elm and Oak species arrives earlier than normal (Table 35). The seed germination algorithm in the simulation excludes the use of the dormancy period check by introducing a 0.6 occurrence probability for any seed to complete the dormancy period. The matching of suitable environmental conditions for seed germination remained unchange. Environmental variations will be broadly the same but with slight differences in each experiment as the virtual ecosystem uses a random variation generator.

Table 35. Compressed migration table for simulating a four-seasonal simulation cycle

Year	Species	Number of Plants	Age of Plants
200	Elm	40	10
230	Oak	40	10
250	Hazel	40	10

The graphs in Figure 121 compare the trend of population growth between the normal and compressed simulation. Except for the Willow, the results demonstrate a broadly similar trend in the population growth with slightly different time lapse in between the growth. The decrease and eventual termination of the Willow species at around year 136 is not due to inter-species competition but rather the effects of a sudden decrease in moisture level hazardous to the species and its progenies. The genetic structure for seed germination of the species is also highly sensitive and that may be the reason the limited amount of seeds produced by parents with low fitness levels does not germinate under that particular condition. Figure 122 shows simulation steps comparing the two simulations. The final results are broadly similar, demonstrating the feasibility of using the compressed version for future studies.

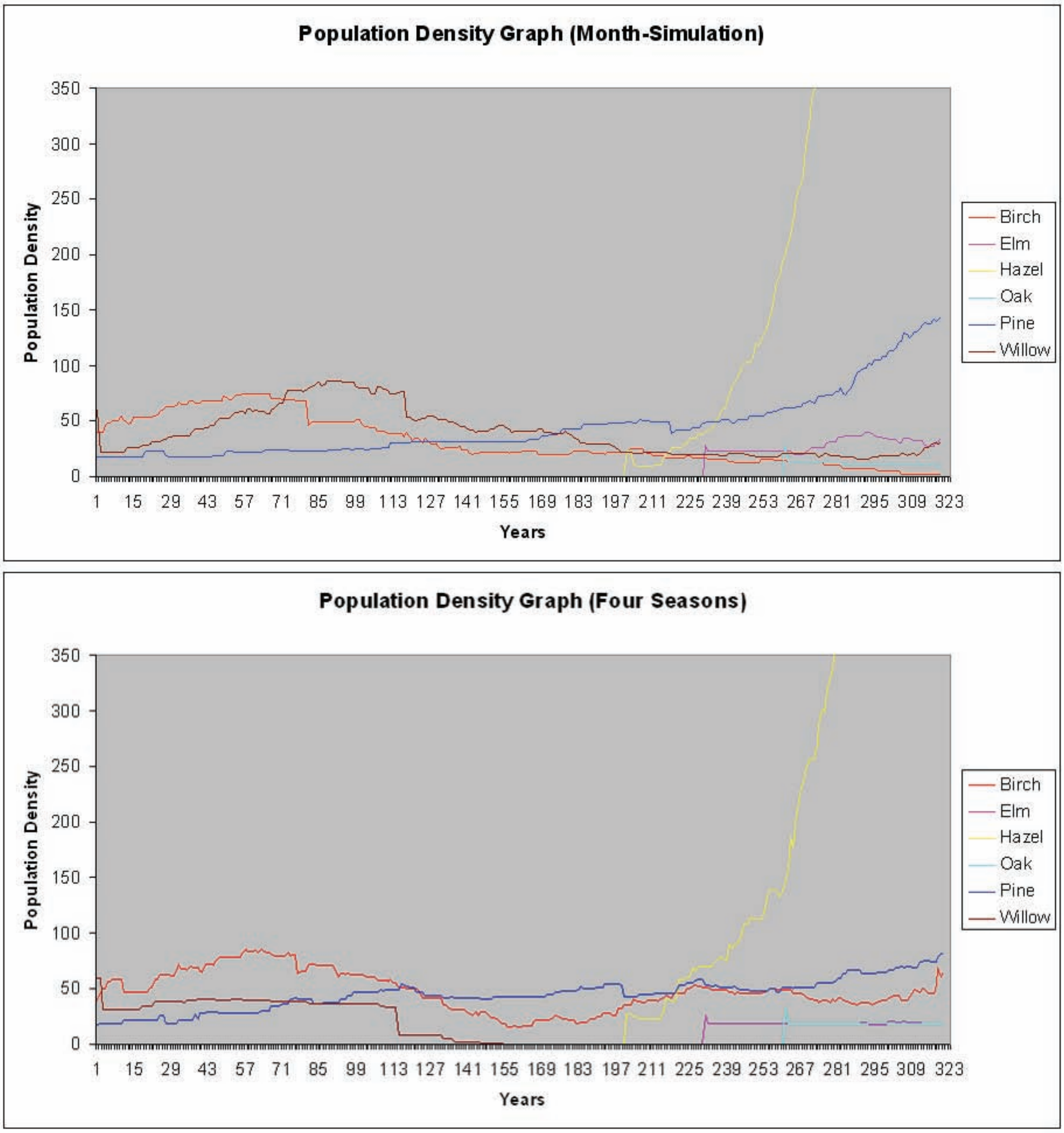


Figure 121. Population graph comparing a normal simulation using an annual monthly cycle and an annual four-seasonal cycle

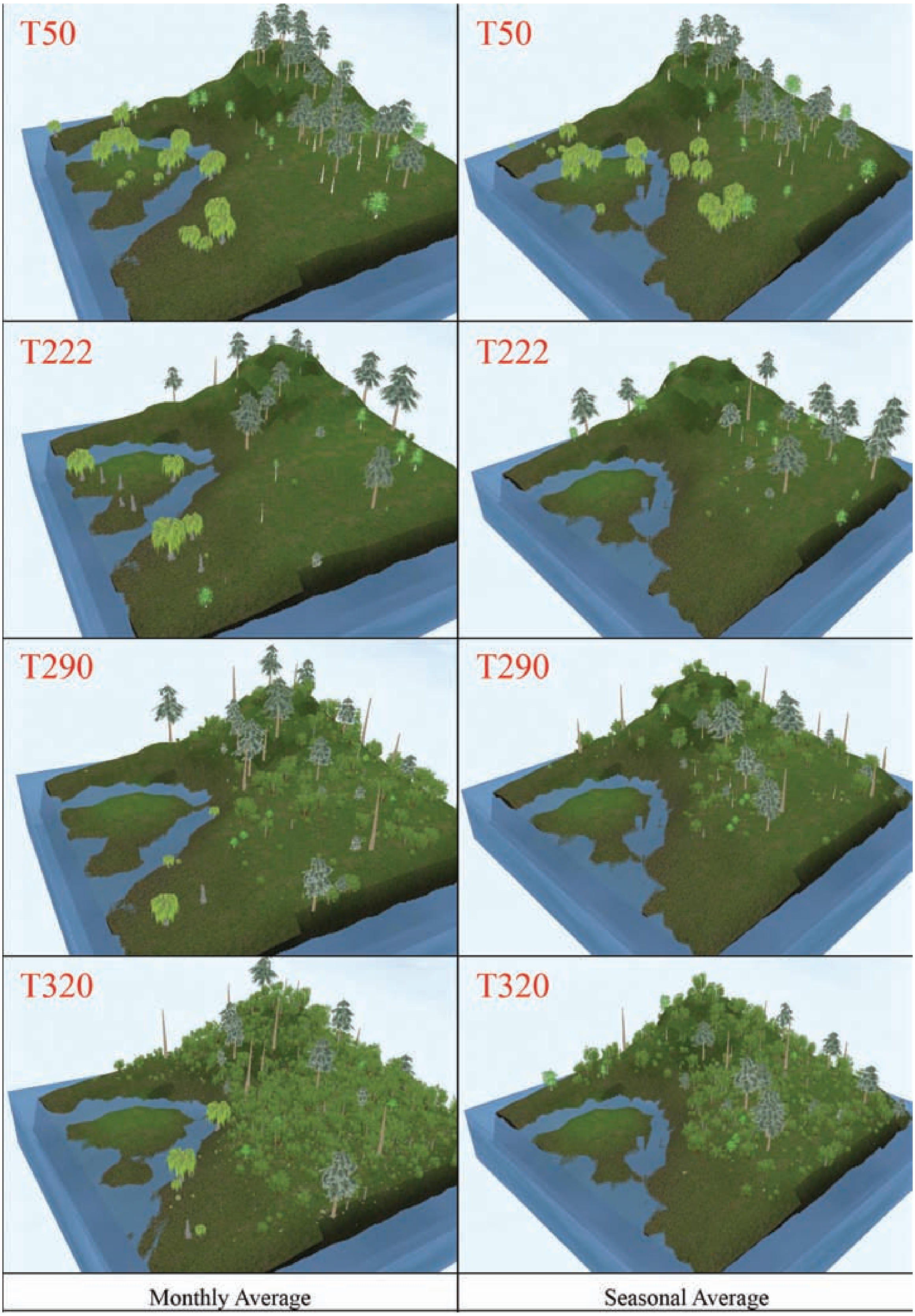


Figure 122. Simulation-sequence comparing the simulation of an annual monthly cycle with a compressed four-seasonal version

6.2.2. Migration of Species and Temperature Variation

Figure 123 shows time sequences of the first scenario at 250 years of growth using the optimised simulation covered in the previous section with migration dataset defined in Table 31 and temperature variation dataset defined in Table 32. The population density graph is shown in Figure 124.

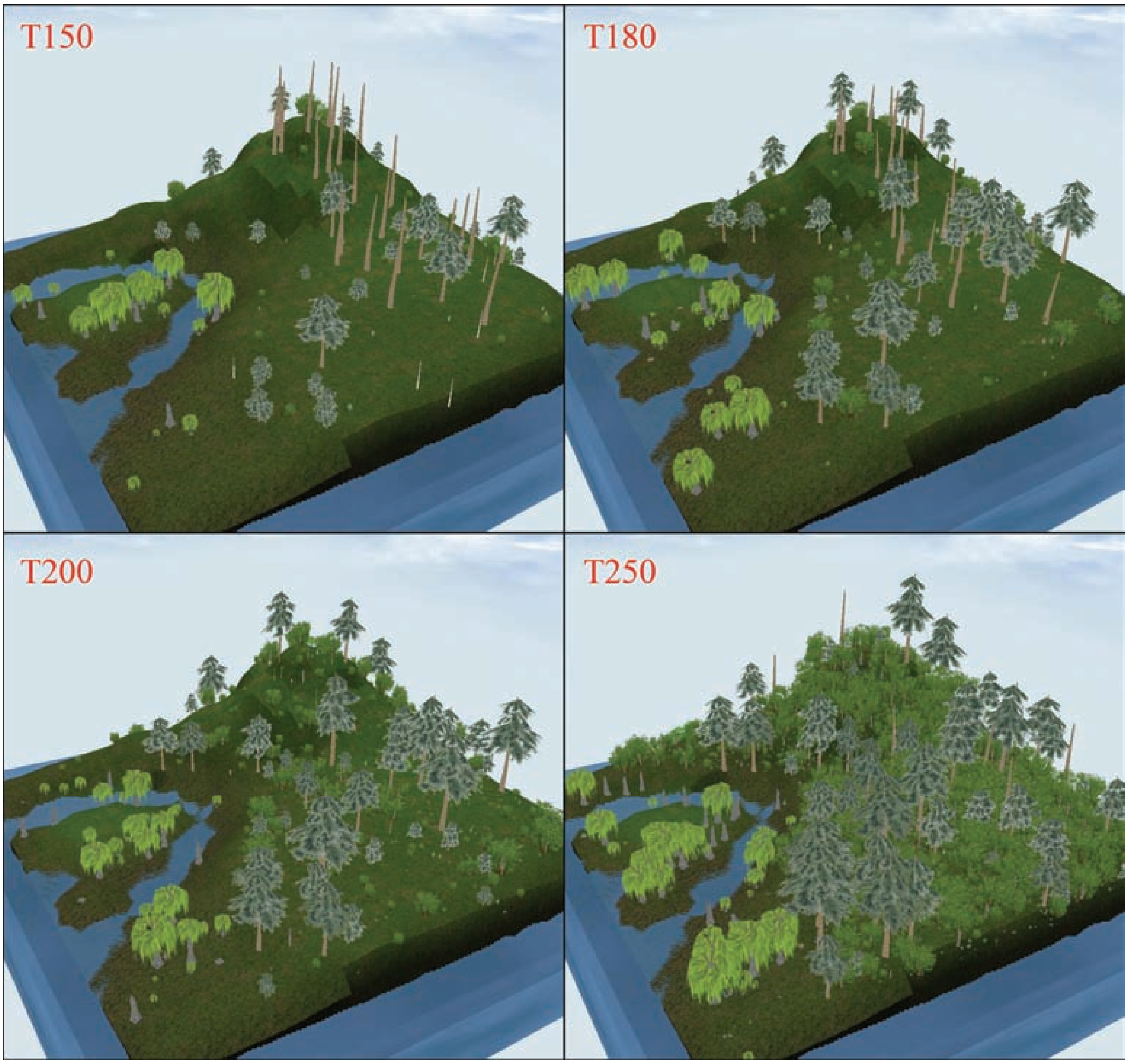


Figure 123. Simulation sequence of a 250 year ecosystem showing plant migration and competition (scenario 1)

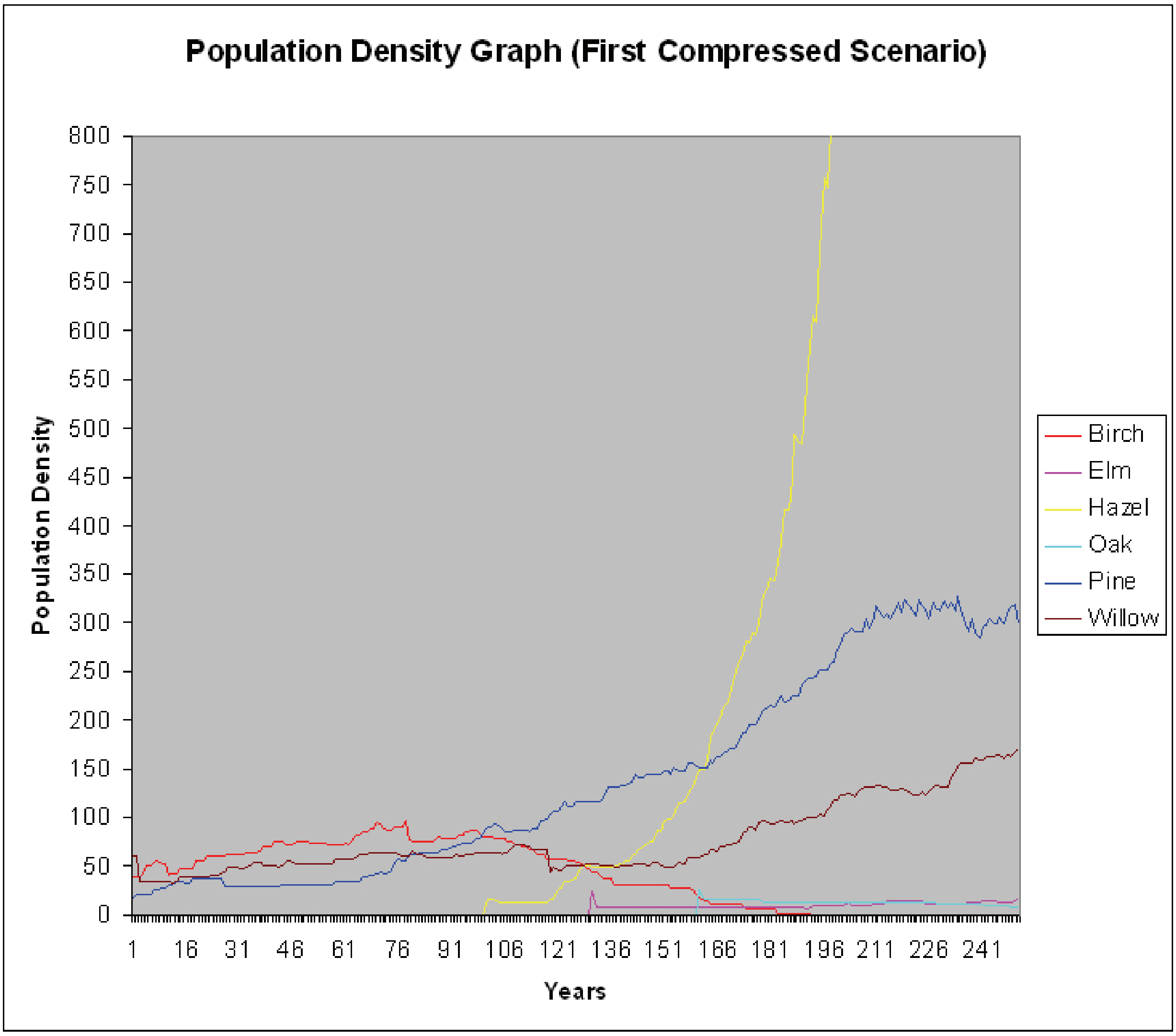


Figure 124. Population density graph showing plant interaction (scenario 1)

The time sequence images and the population graph above showed the migration, growth and colonisation of Hazel from year 100 onwards. The graph showed a phenomenal growth due to suitability of habitat for the species. Birches reproduce at a consistent rate until the arrival of Hazel, which brought a gradual decline in its population. The dense distribution of Hazels did not affect the Pines however. This may be due to the strong adaptability and constitution of the Pine species in this particular environment. The Willow has a healthy population as they are not affected by any other species suited to its habitat, near river banks where the moisture content is highest. The population of Oaks and Elms on the other hand remained relatively constant. This effect of population interaction between each species in the particular setting has some correlations with the pollen percentage diagram seen in Bennett's study [12].

Figure 125 shows time sequences of the second scenario at 318 years of growth. Migration dataset is defined in Table 33 and temperature variation dataset is defined in Table 34. The population density graph is shown in Figure 126.

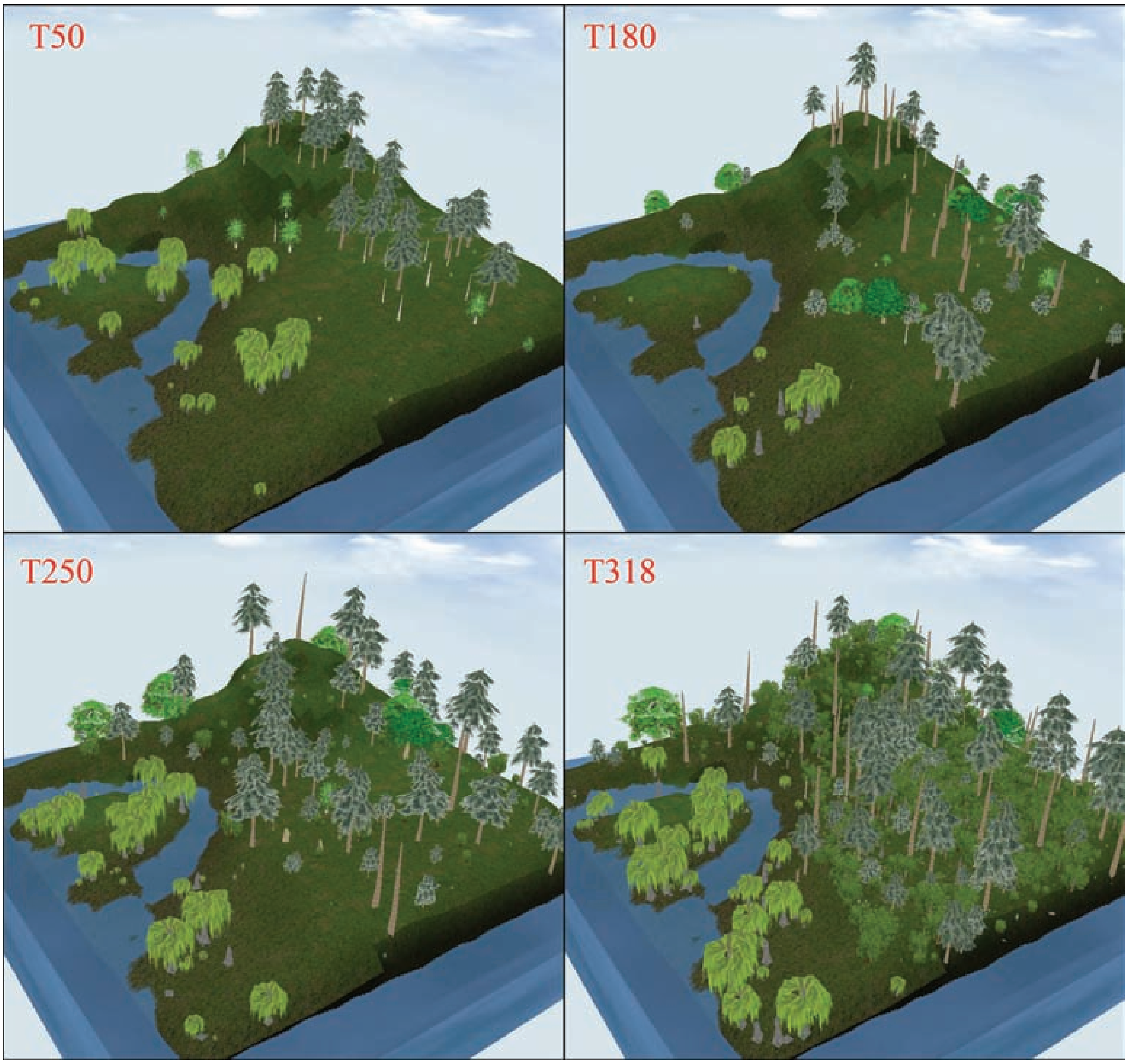


Figure 125. Simulation sequence of a 318 year ecosystem showing plant migration and competition (scenario 2)

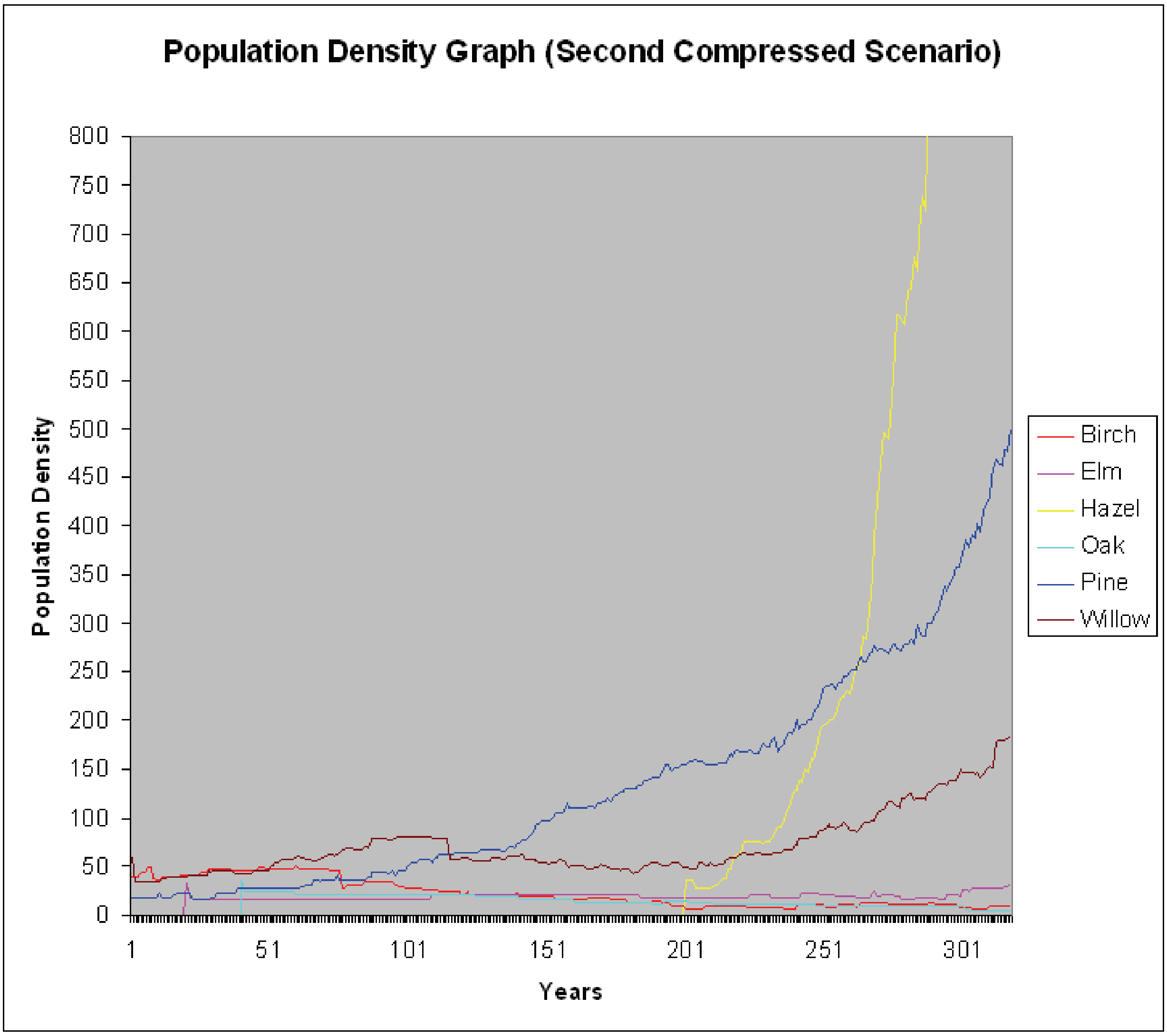


Figure 126. Population density graph showing plant interaction (scenario 2)

The time sequence and population for the second scenario showed relatively similar patterns of growth with the first. The Pines and Willows have a healthy rate of growth. The population of Birches, Oaks, and Elms showed a gradual decline over the years due to the speedier growth of three other species.

6.3. Reconstructing the Shotton River Valley

In this section, the Artificial Life model is applied to determine the distribution of vegetation communities on segments of the Shotton river valley (Figure 127). Characteristics of the undergrowth and distribution of herbaceous plants sampled from the landscape section are studied in Section 6.3.4. Figure 128, Figure 133, and Figure 135 are definitions of topology and ground conditions for soil acidity, depth, and texture. In each definition, a higher concentration has a higher greyscale levels. Darker areas in the definition for soil depth are deeper. Higher greyscale levels in the definition for ground texture shows harder surfaces. Prior to the simulation, a range of relatively matured trees were randomly distributed across the landscapes using the *SeederEngine* Map Editor. Using the optimisation technique, the trees were allowed to settle into their ecological niches at the start of the simulation. Reproduction occurred in the following year and as seedlings saturated the landscape, forests were formed. Concentration of species on the landscape shows the suitability of the habitat for that species. The results of the study are presented in the sub-sections.

Figure 127. Target reconstruction landscape segments from the Shotton River Valley

6.3.1. Segment 1

In the reconstruction of segment 1, the landscape is divided into four quadrants in the simulation for ease of viewing and speed of simulation (Figure 128). Figure 129 to Figure 132 shows the outcome of the simulation and population density graphs for each section of the landscape.

The pine species has the lowest population in the top left (Figure 129) and bottom right (Figure 132) quadrant. Population densities of Hazels are similar in all segments although the rate of growth is slightly lower at the bottom right segment (Figure 132). The Birch species are found only at the top left and bottom right segments at a decreasingly low density. The population did not persist for long in the simulation. The population of Elm trees are low in all segments but an increase in growth is seen at the top right segment. Except for the bottom left segment, the population of Oaks have a stable increase throughout the landscape. Except for the bottom right segment, Willows dot the river banks and are in abundance near the mouth of the stream at the bottom left segment.

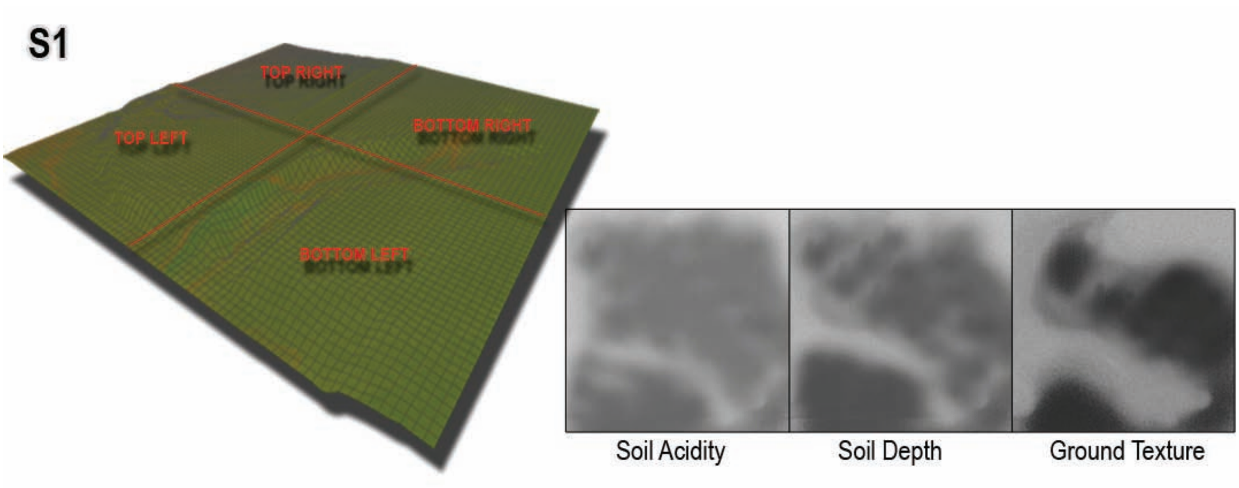


Figure 128. Topology for the Segment 1 landscape and its soil types and ground info

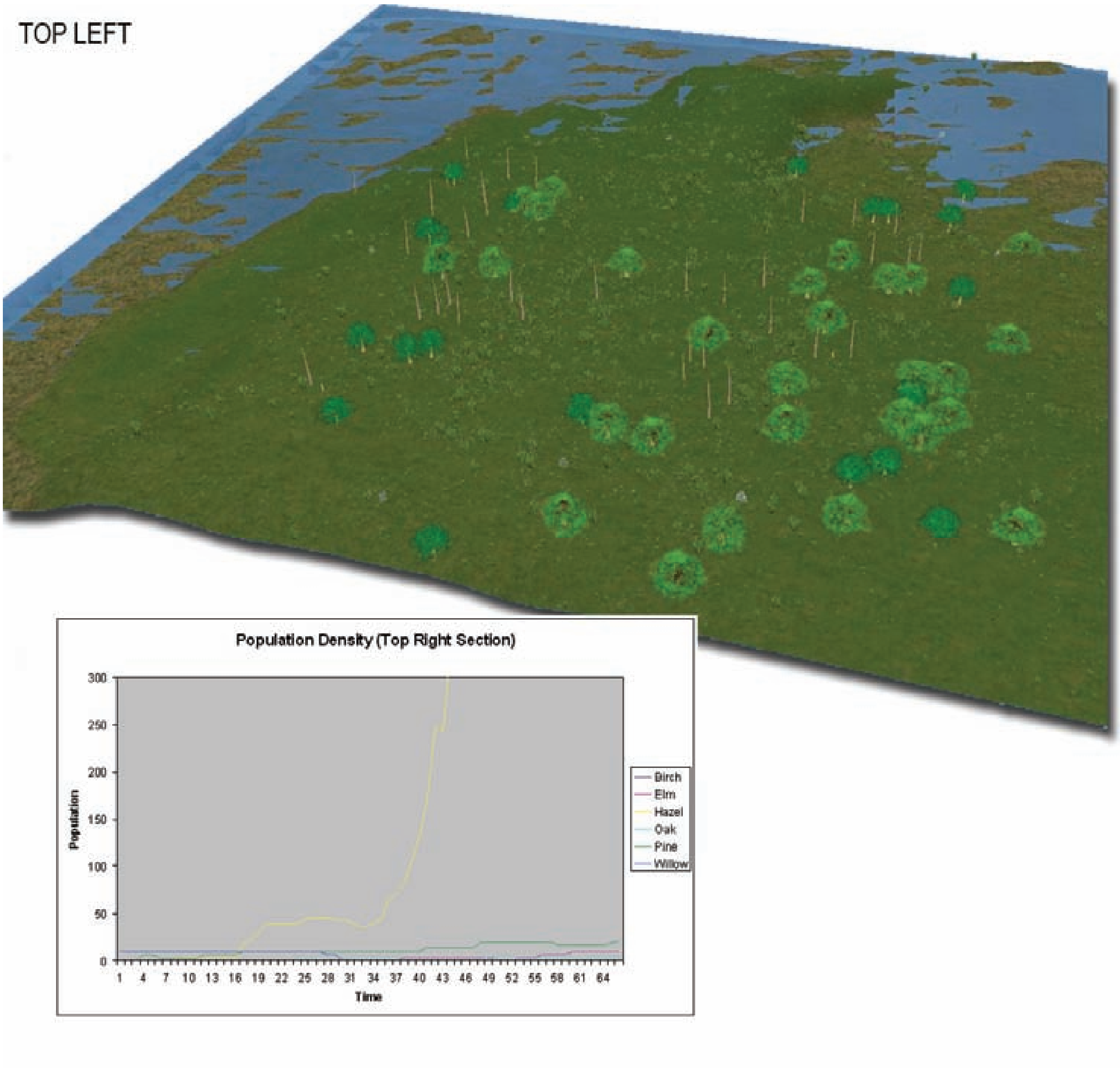


Figure 129. Simulation of Segment 1 landscape from the Shotton river valley: top left section

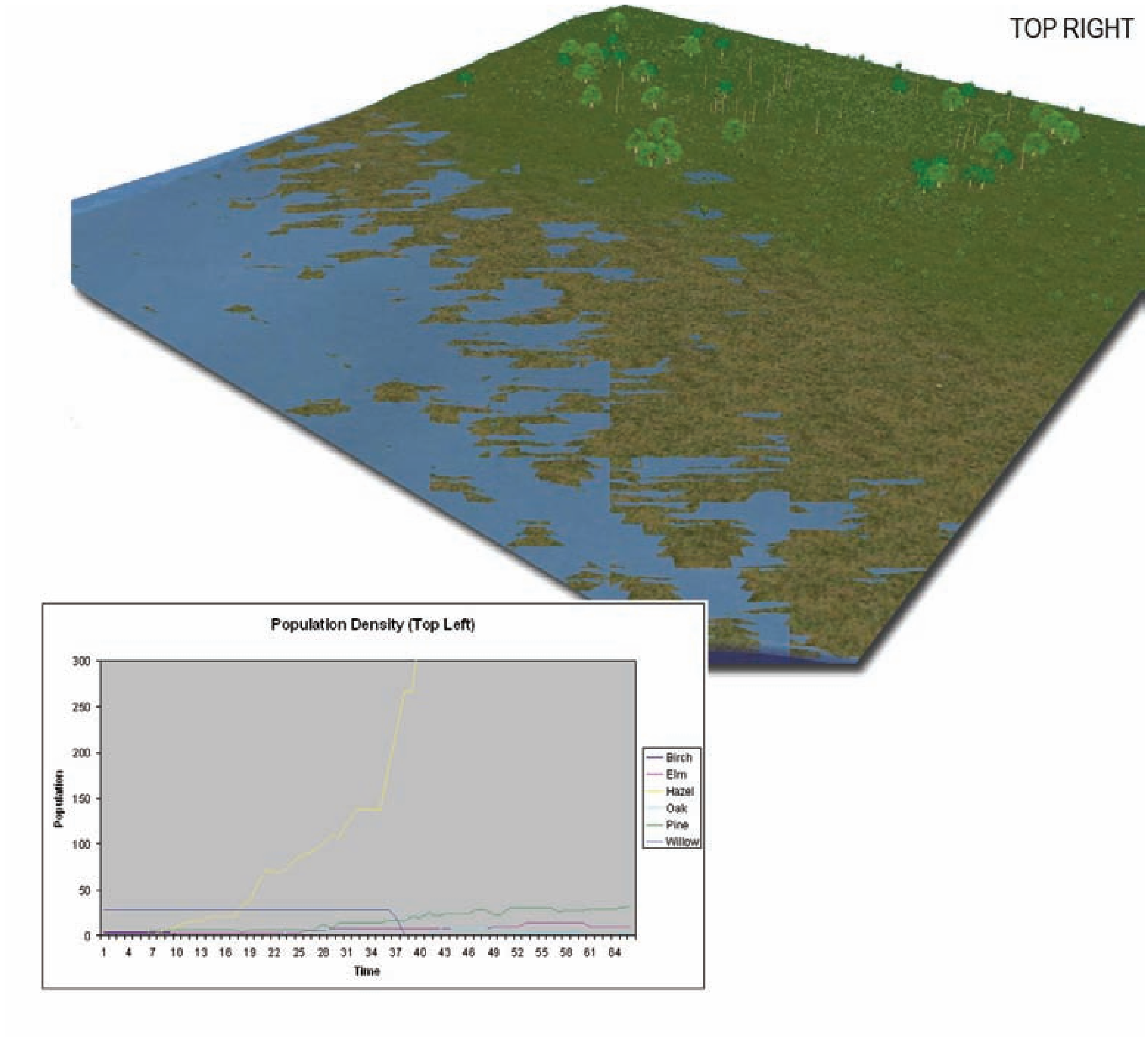


Figure 130. Simulation of Segment 1 landscape from the Shotton river valley: top right section

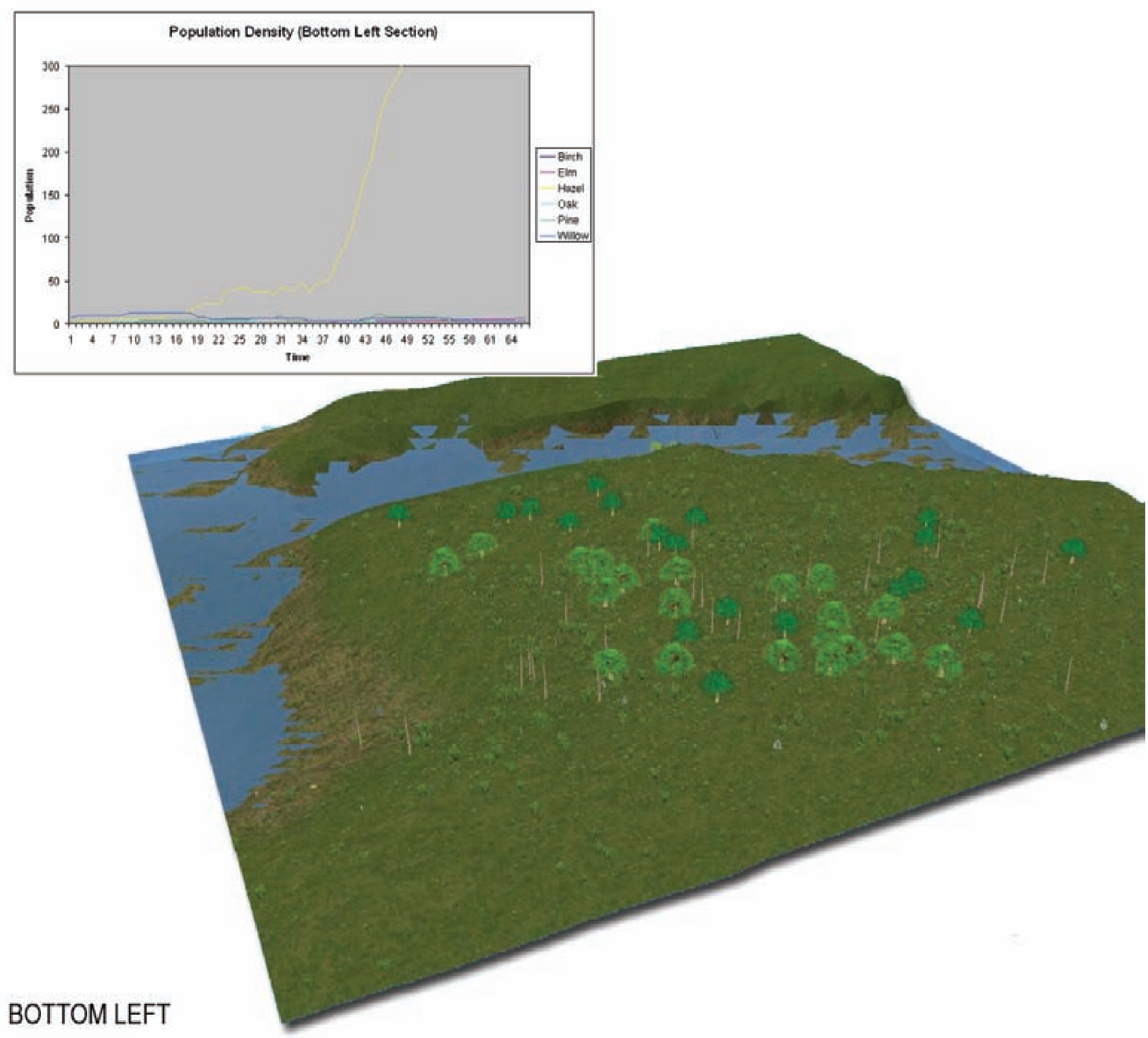


Figure 131. Simulation of Segment 1 landscape from the Shotton river valley: bottom left section

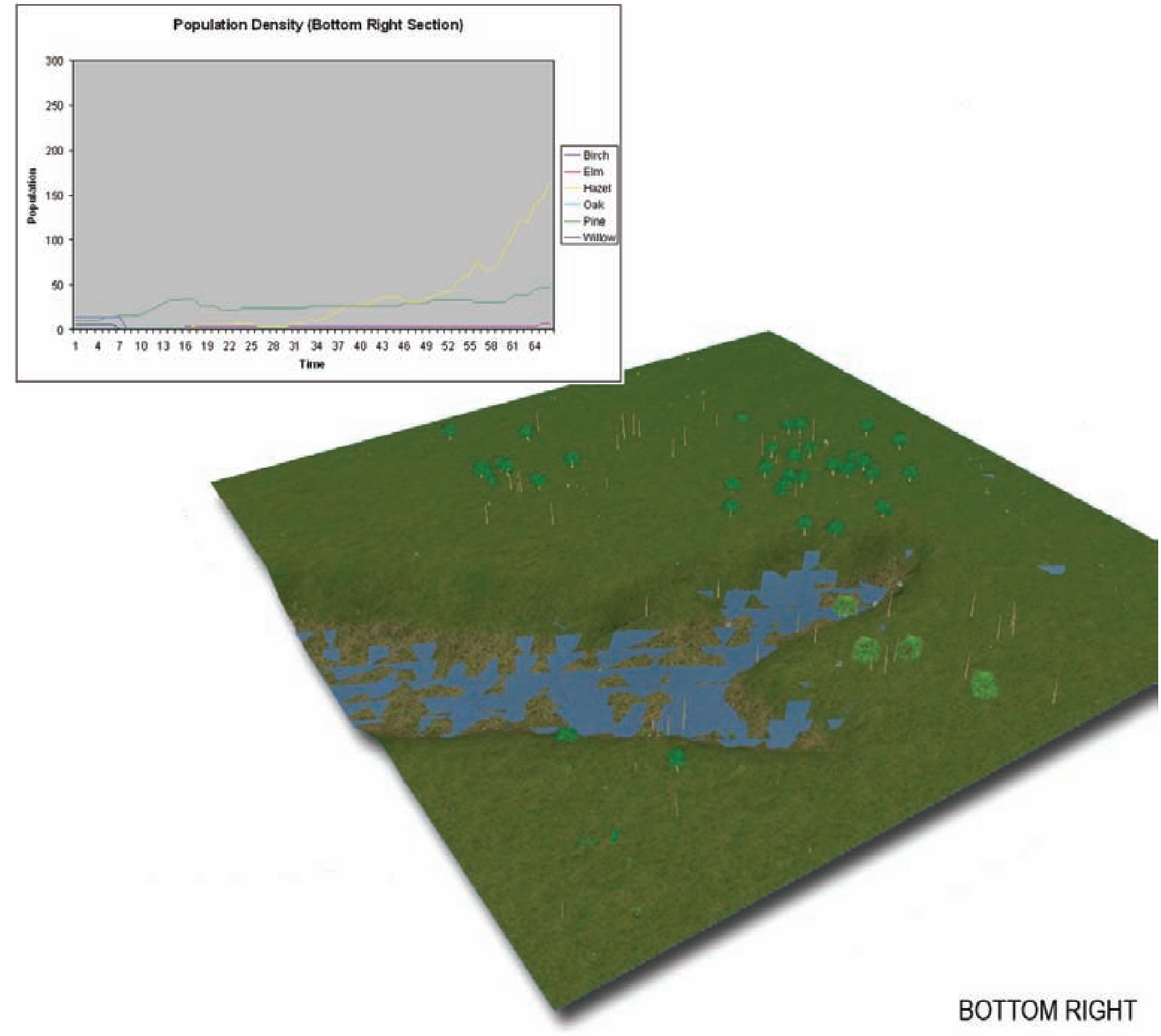


Figure 132. Simulation of Segment 1 landscape from the Shotton river valley: bottom right section

6.3.2. Segment 2

Figure 134 is a view of segment 2 of the landscape with the population growth and density graph shown in the inset. The landscape has a higher concentration of Elm, Oak, and Pine. Willows and especially Birches did not persist for long before they fade from the terrain.

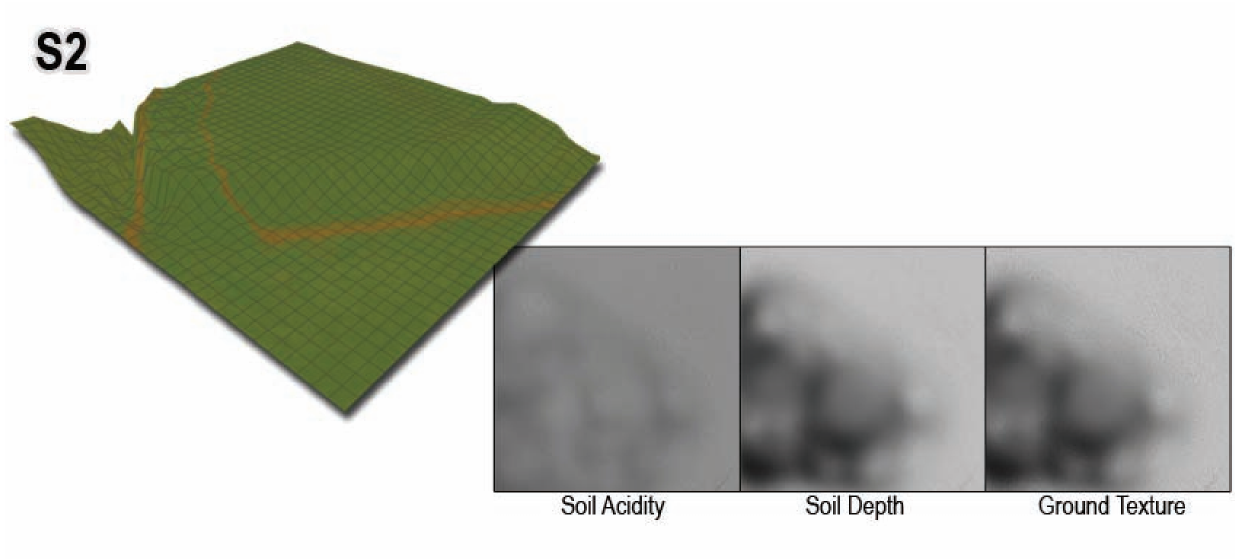


Figure 133. Topology for Segment 2 landscape and its soil types and ground info

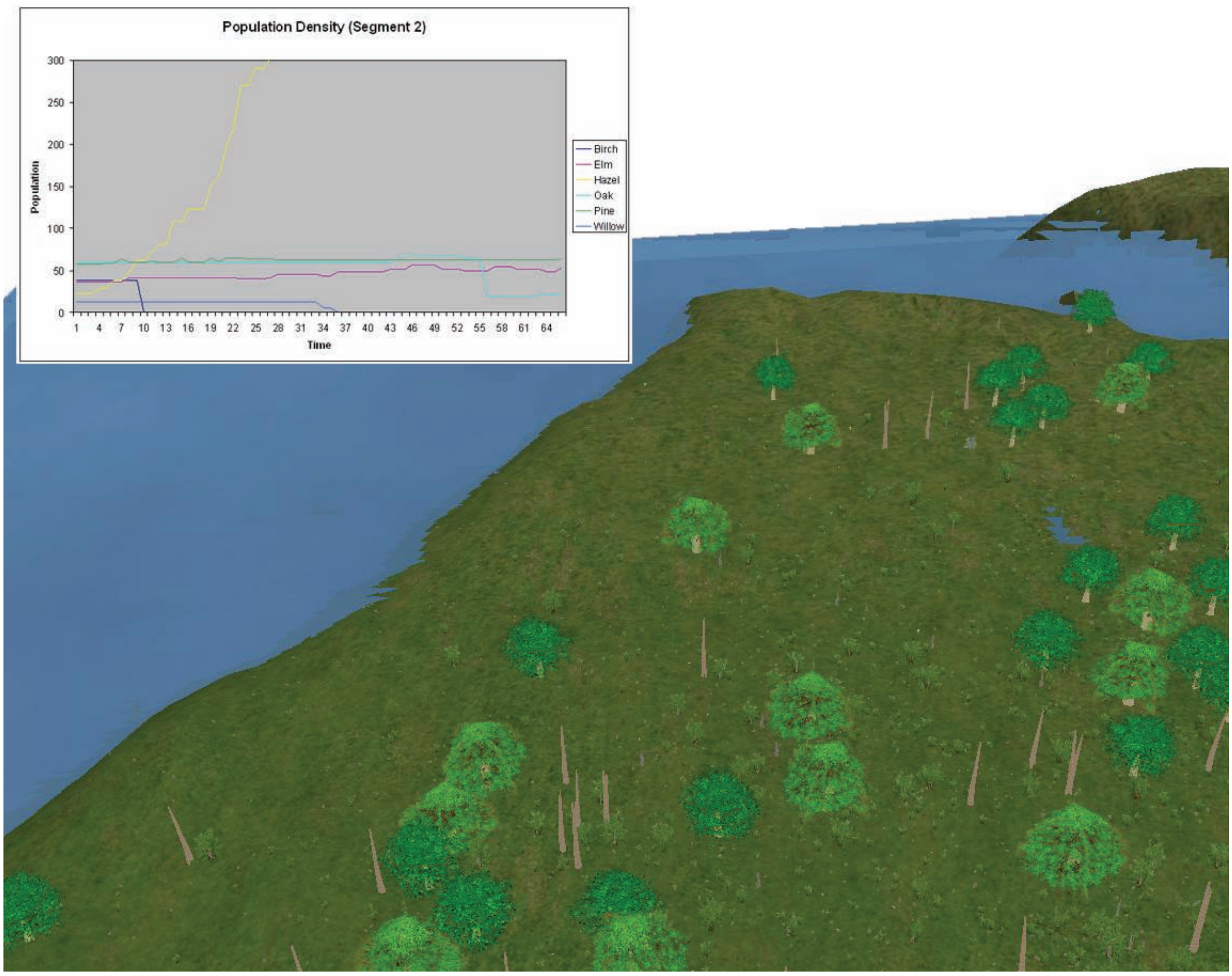


Figure 134. Simulation of Segment 2 landscape from the Shotton river valley

6.3.3. Segment 3

Figure 136 is a view of segment 3 of the landscape with the population growth and density graph shown in the inset. The landscape has a healthy growth of Pine trees. Elm, Oak, and Willow remained relatively stable after the initial population has died. Birches are unable to adapt to the conditions of the landscape and therefore, disappeared from the landscape.

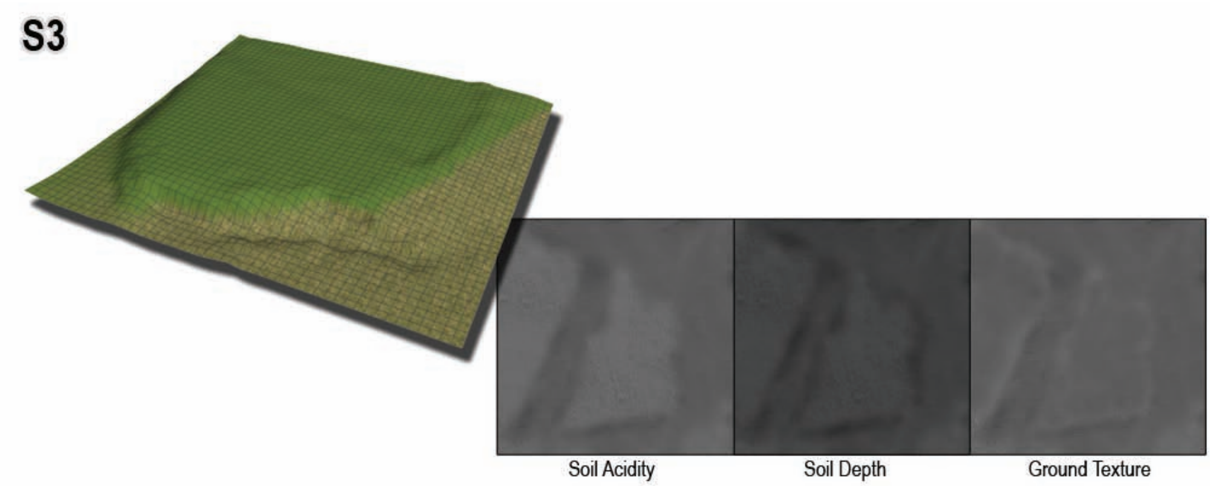


Figure 135. Topology for Segment 3 landscape and its soil types and ground info

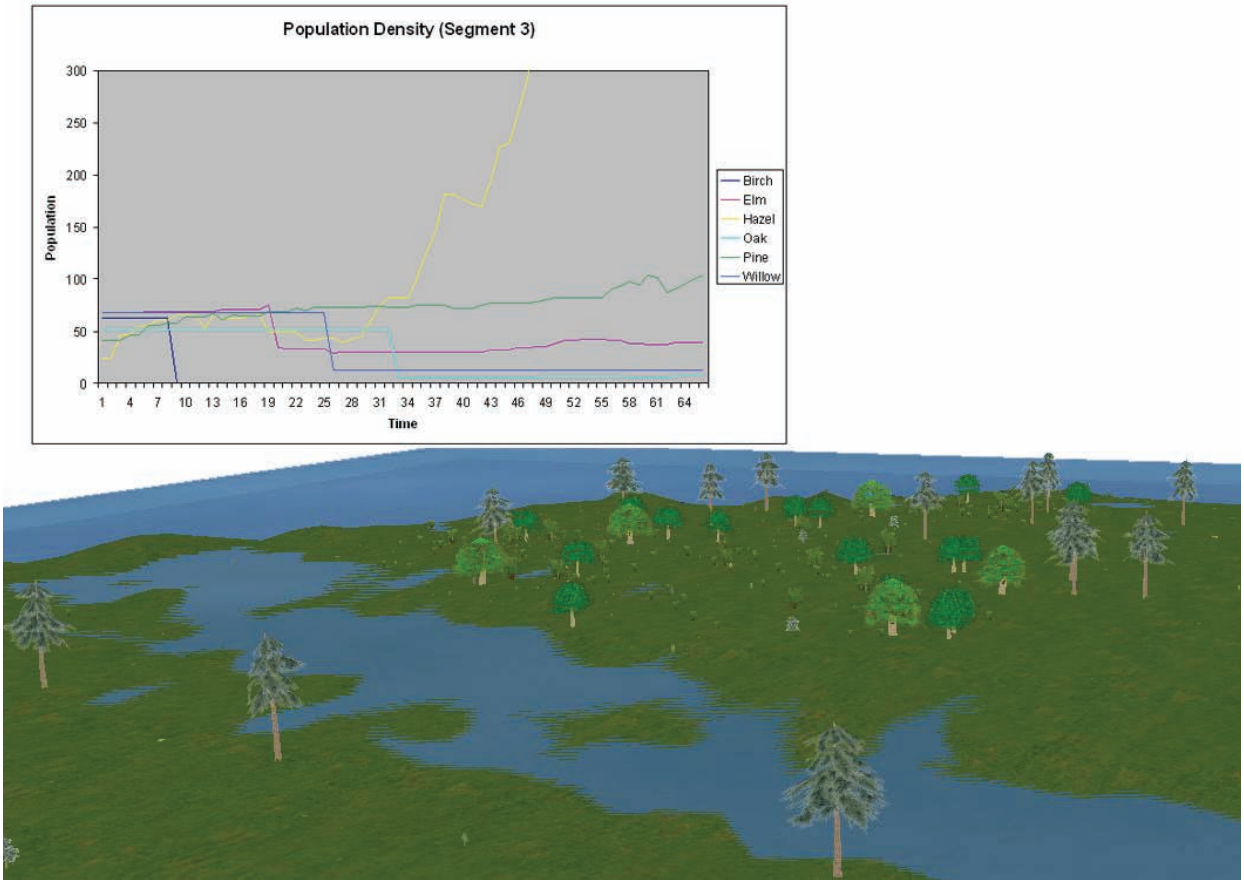


Figure 136. Simulation of Segment 3 landscape from the Shotton river valley

6.3.4. Growth Characteristics of Herbaceous Plants

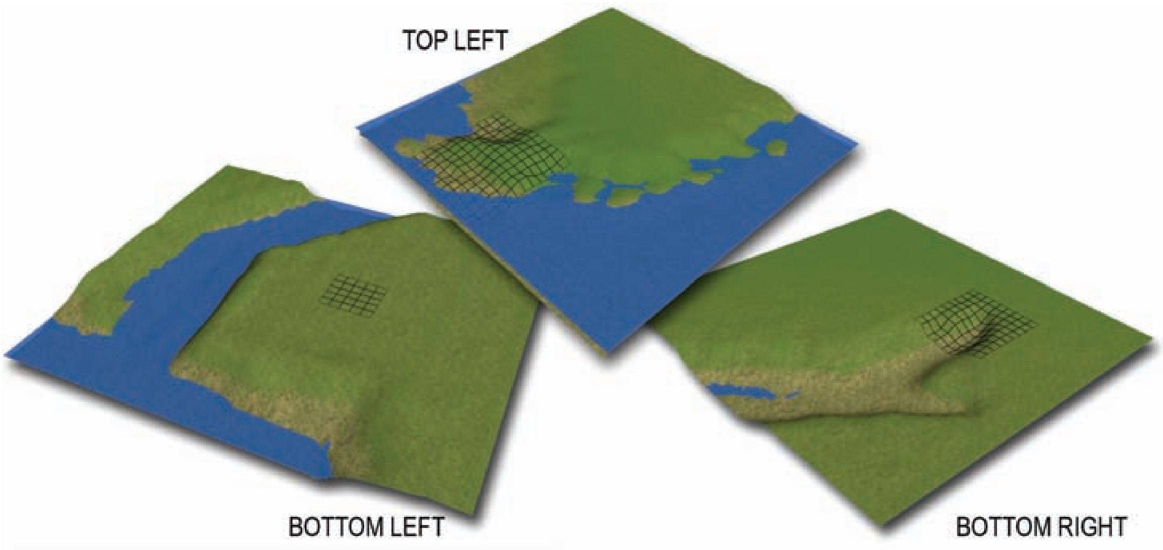


Figure 137. Segment 1 quadrants landscape samples for observing characteristics of undergrowth and herbaceous plants

Three strategic locations are selected from quadrants of segment 1 of the landscape for determining the growth characteristics of herbaceous plants in open space and the undergrowth. The plots of landscape described as wireframes can be seen in Figure 137. Figure 138 to Figure 140 shows the outcome of the simulation. Unlike the woodland types in the previous sections, the growth and colonisation of herbaceous plants remained relatively similar across the landscape. Ferns are scattered across the landscape but appeared in increasing frequencies and clusters around woodlands and under the shades of larger trees, such as those seen in Figure 138. In contrast, flowering plants appeared more frequently in open spaces. In Figure 140, the distribution of plants is lowest around the base of the valley where soil moisture is increasingly higher.

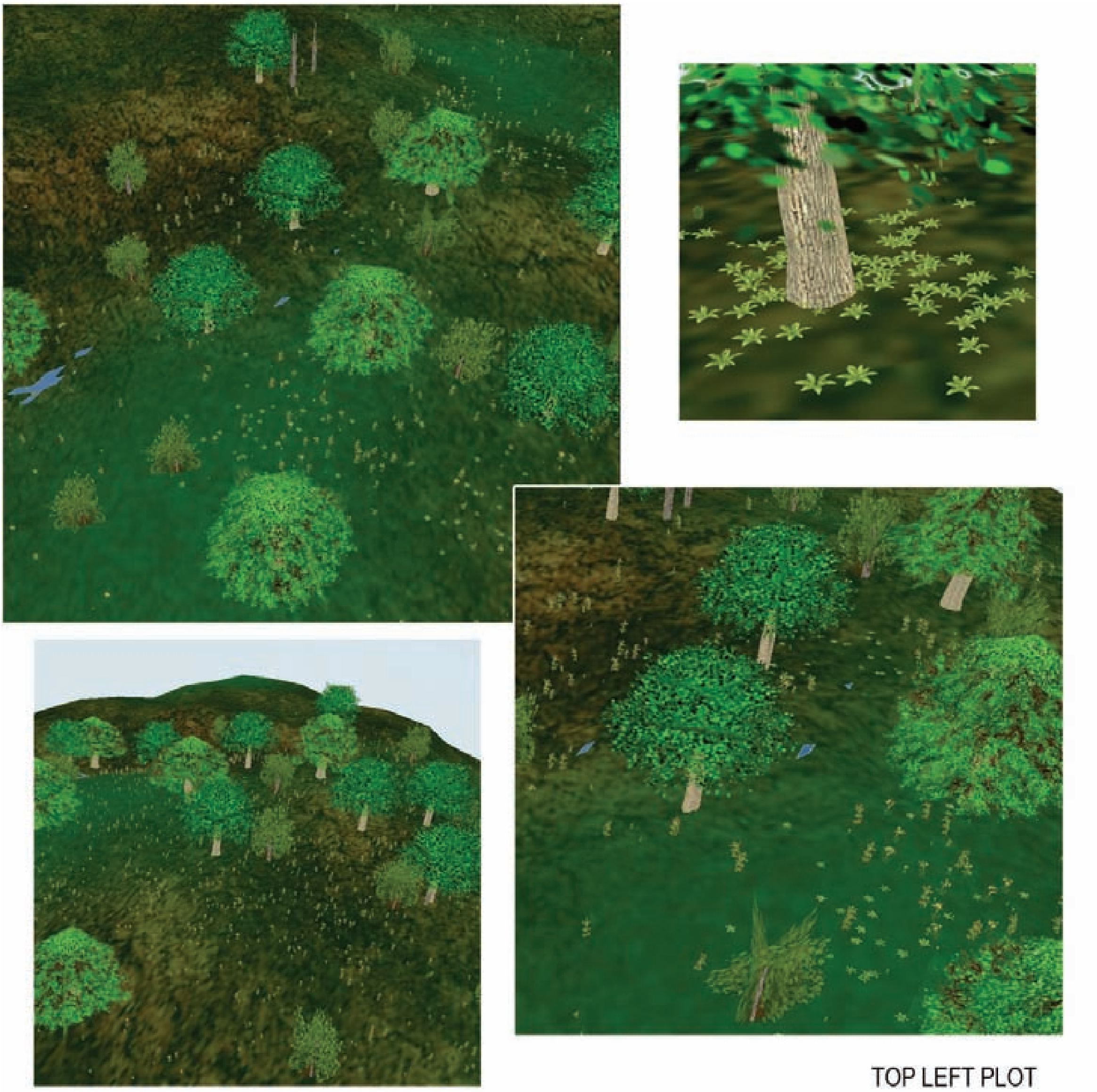


Figure 138. Segment 1 landscape samplings for observing characteristics of undergrowth and herbaceous plants

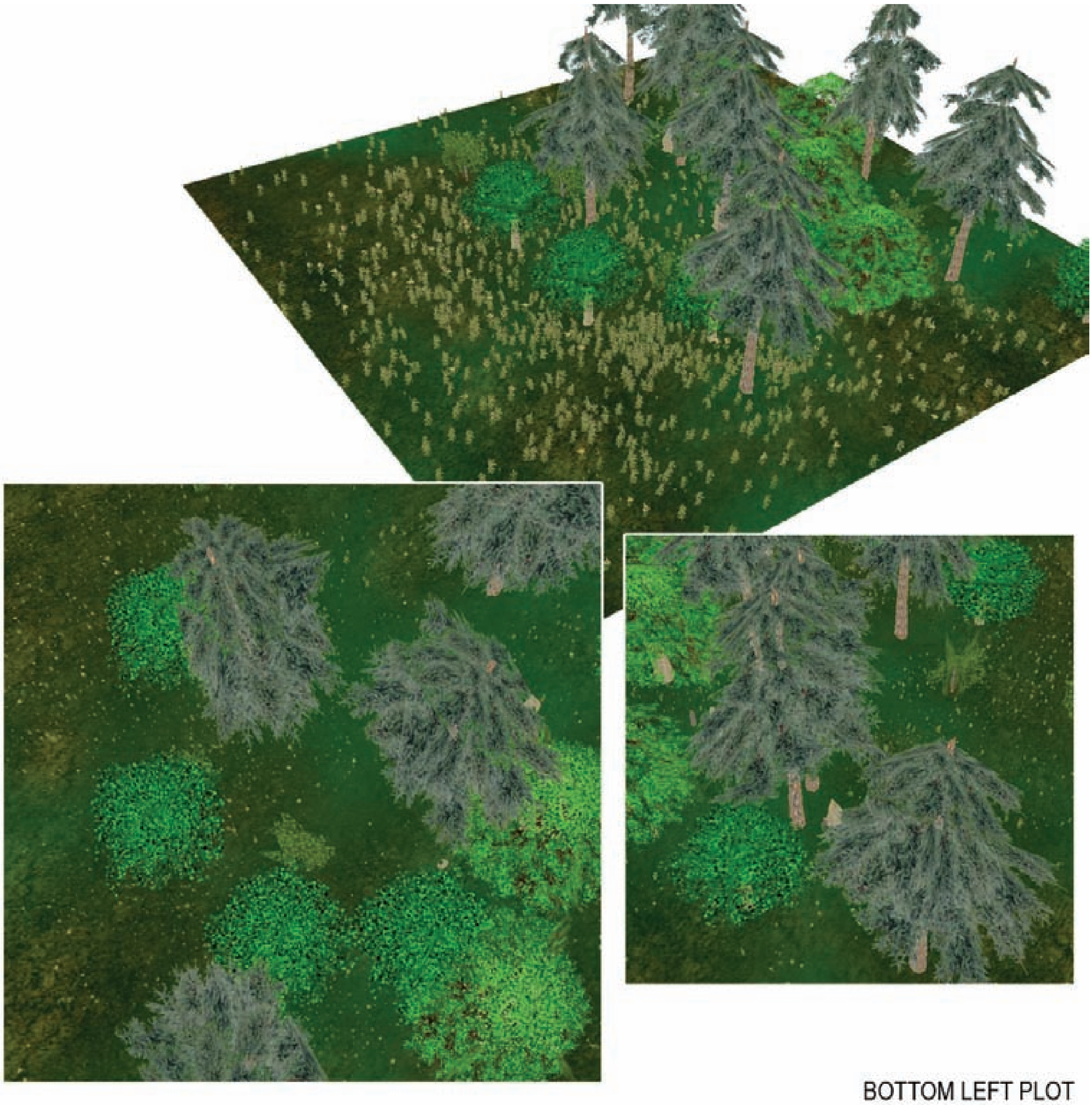


Figure 139. Segment 1 landscape samplings for observing characteristics of undergrowth and herbaceous plants

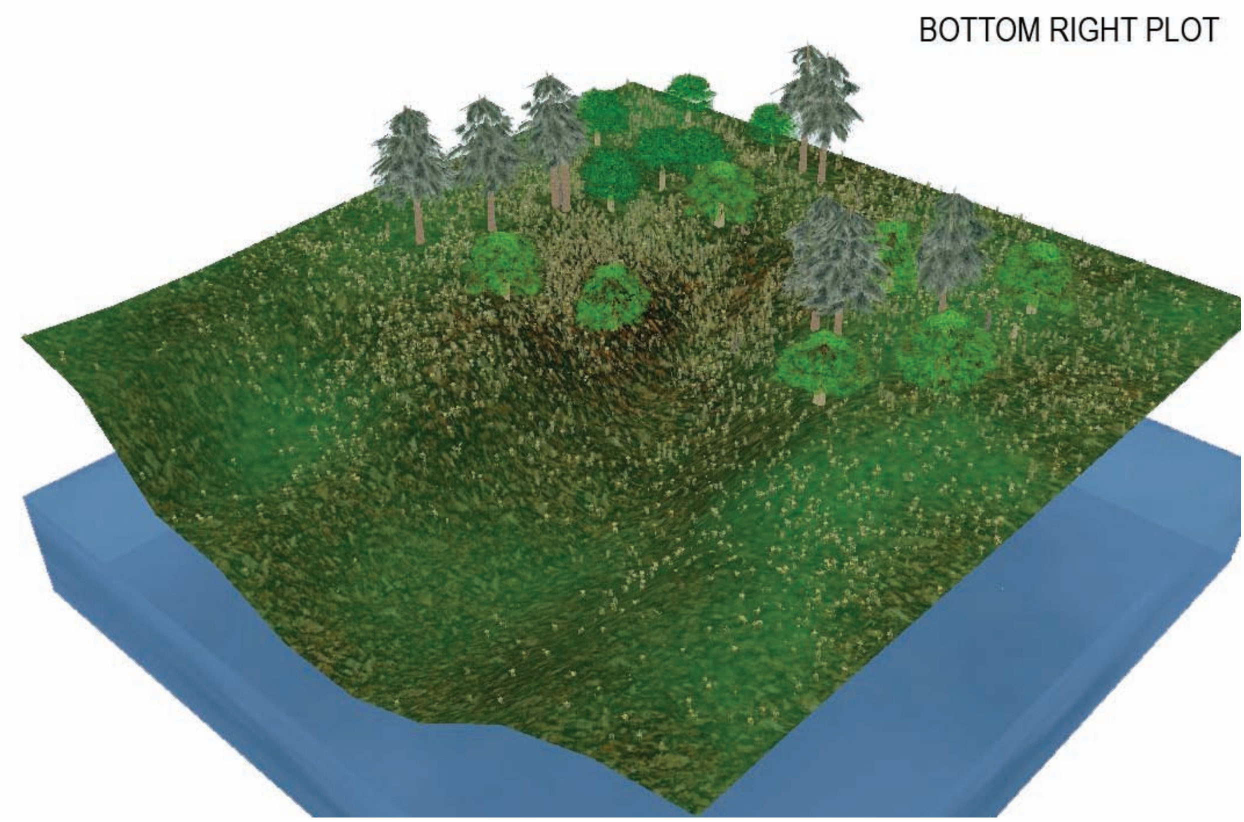


Figure 140. Segment 1 landscape samplings for observing characteristics of undergrowth and herbaceous plants

The close-up screenshots of an additional simulation is shown in Figure 141. The purpose of the simulation is to observe the detailed effects of growth and distribution of herbaceous plants on a landscape with similar settings as compared to the segments shown previously. The results yielded similar effects with Ferns especially dense under the canopy of trees. Water Pepper, an additional Mesolithic species added into the model has a higher population density around the damp regions of the landscape and even within the shallow pond. Stinging nettles and Hairy Hawkweeds dot the landscape but are found in more abundance on dry grounds.

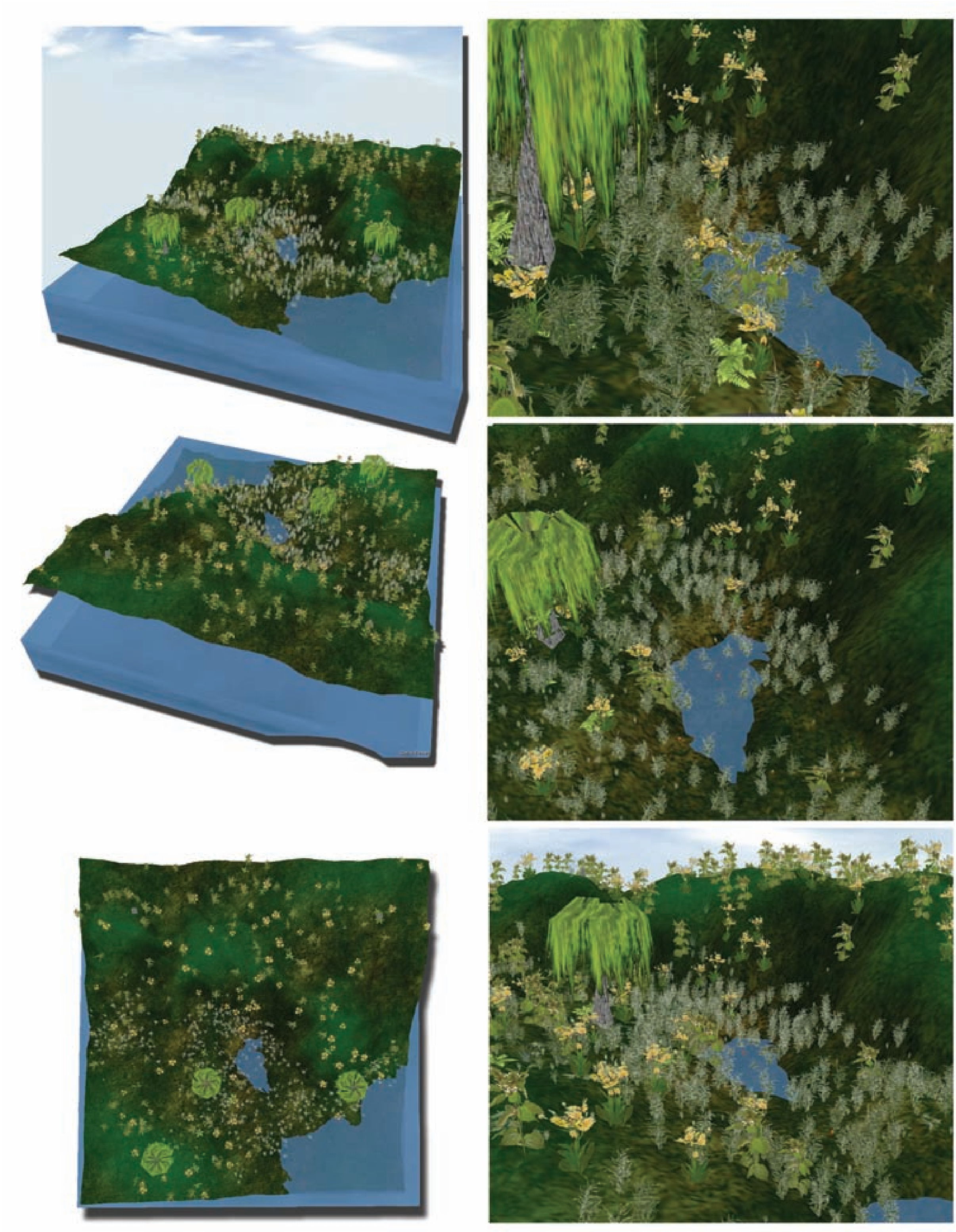


Figure 141. A micro view of the characteristics of herbaceous plants

6.4. Interactive Virtual Environment

In section 1.3, strategic landscape segments from the Shotton river valley were recreated using the Artificial Life-based vegetation model within the *SeederEngine* Virtual Environment. In order to augment the experiential aspect of archaeological interpretations of the landscape, Crytek's CryEngine™ were used for reconstructing the river valley based on the pattern characteristics of the growth and distribution of vegetation communities. As described in Chapter 3, CryEngine™ has many inbuilt functionalities for special effects, shaders and outdoor natural rendering optimisations, etc. Therefore, using the engine as an interactive Virtual Environment will guarantee a higher quality of experience. Locations of woodland types were identified relative to the landscape and placed within CryEngine™'s Virtual Environment. Locations and habitat of herbaceous species references the characteristic growth and distribution of the *SeederEngine* Artificial Life environment. The images below showed the Virtual Heritage reconstruction.

Figure 142. The Shotton river valley interactive Virtual Environment

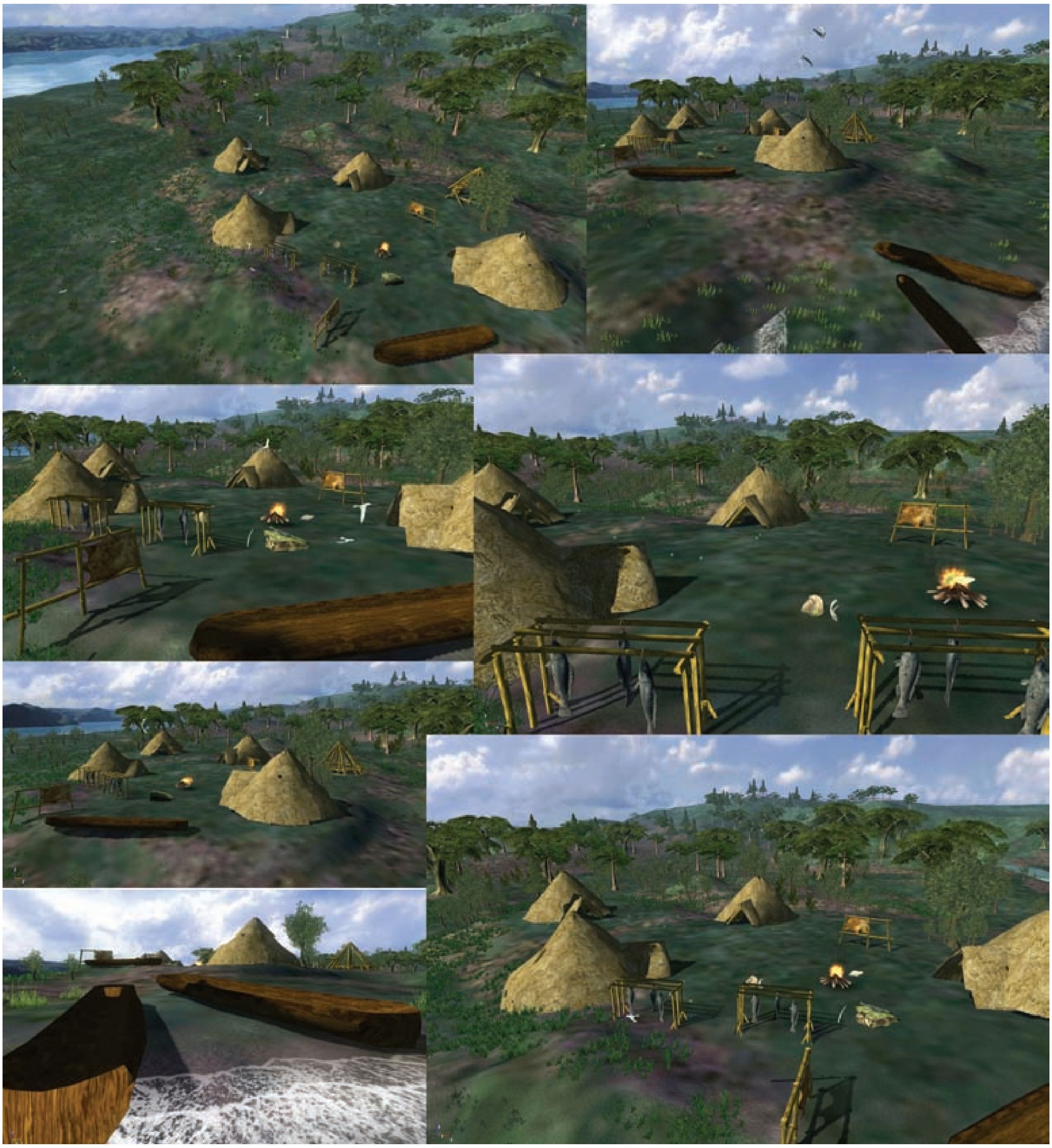


Figure 143. The Shotton river valley: village scene

Figure 144. The Shotton river valley: river scenes

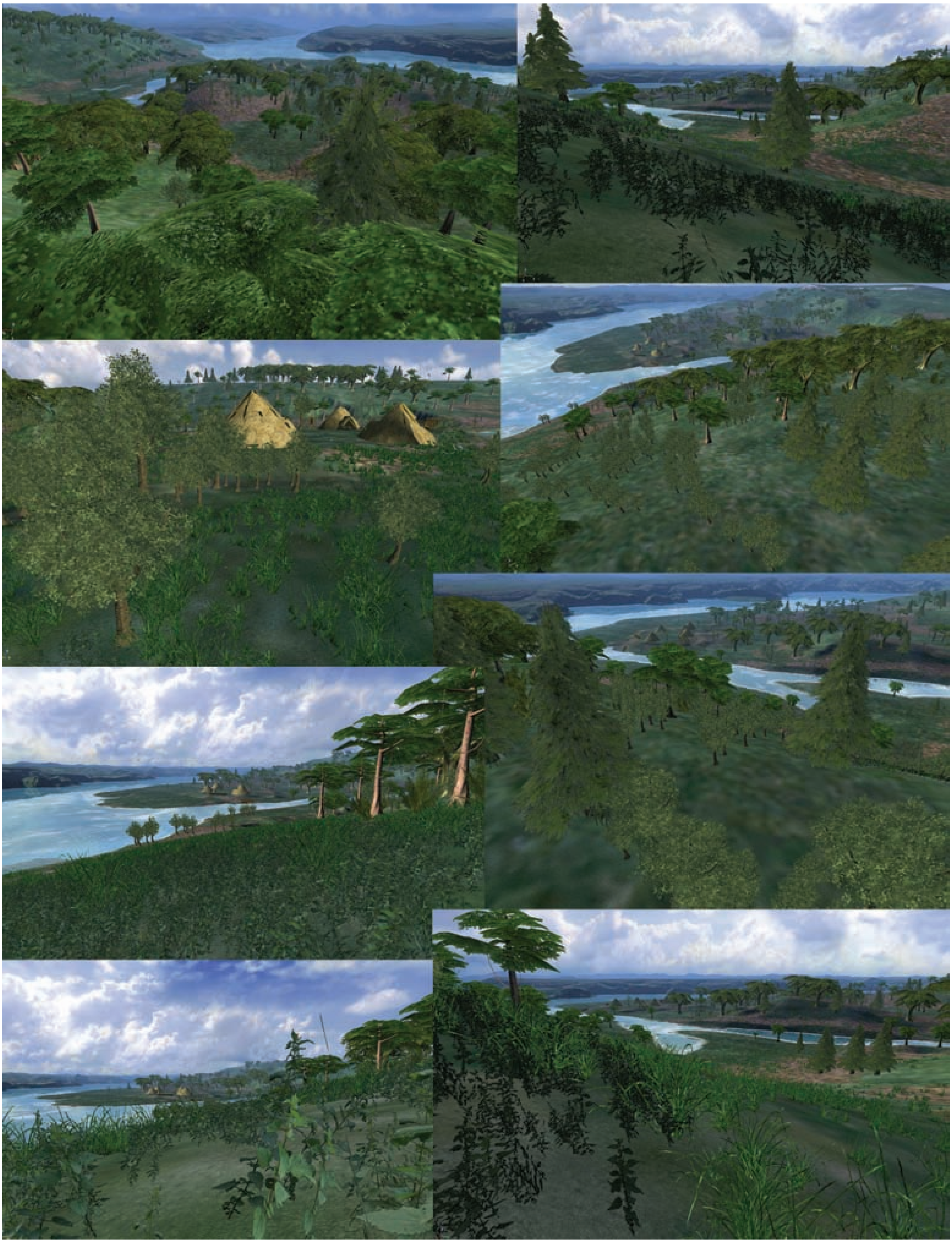


Figure 145. The Shotton river valley: surroundings

6.5. Conclusion

Both the processual and experiential/sensual approach in the study of prehistoric sites and landscapes are important. While a great deal of modern landscape archaeological interpretations depended upon scientific modelling, it is become recognised that the experience of 'being in the world' is important in the interpretation of spatial relationships of monuments and artefacts in an archaeological site. Until recently, this integration of the quantitative and the qualitative approach was uncommon. However, via experimental set ups, scientists in the Virtual Heritage domains are beginning to see the potentials of it in a wide range of archaeological applications.

This chapter presents a novel approach for the reconstruction of ancient landscapes via the fusion of Artificial Life and Virtual Environment. The reconstructions, which consisted of landscape samplings from the Shotton river valley are based on the vegetation and environmental models developed in Chapter 4 and an optimised simulation concept evaluated and verified in this chapter. Vegetations of major woodlands species and herbaceous plants were 'grown' on the landscape samplings using the *SeederEngine* Virtual Environment simulating Mesolithic climates and environments. The distributions of vegetation were later reproduced within *CryTek*'s *CryEngine*™ for augmenting the experiential aspect of archaeological exploration and interpretations. Finally, a review of the growth segments by the archaeological team belonging to this collaborative project revealed a likely settlement area. Based on the study, 3D models of Mesolithic houses and artefacts developed in the early technical investigations (Chapter 3) were added onto the scene. Living entities such as insects, flocking birds, schooling fishes, and land animals were also added as part of the living environment.

The overall effects witnessed in the *CryEngine* interactive 3D environment grown with the Artificial Life vegetation were very realistic, demonstrating the feasibility of the fusion of Artificial Life and Virtual Environment for Virtual Heritage reconstructions.

Chapter 7

Conclusions and Future Work

7.1. Introduction

Virtual Heritage applications involving the reconstruction of virtual worlds in particular require much more than a visually pleasing yet lifeless environment. The advent of Artificial Life research is changing the possibilities of a Virtual Heritage site to encompass living Virtual Environments inhabited by intelligent entities or agents with characteristics of life. As of today, the fusion of the two currently highly popular fields, that is, the integration of Virtual Environment with Artificial Life has become instrumental in the restoration, preservation, and reconstruction of just a handful of world heritage sites. A survey of Virtual Heritage projects (2.2) have shown that a truly successful application, one that could educate and impact upon the user's perception and value towards a site, does not depend upon the mere imitation of the site via accurate 3D reconstruction, realistic visualisation, and simple walkthroughs. In fact, an important feature considered lacking in today's Virtual Heritage sites is the addition of 'living' environment and 'responsive' avatars or agents with characteristics of life. The survey showed that most interactive media types used were linear, static, non-evolvable, and unresponsive, one that could not sufficiently enhance the user experience.

The development of Virtual Heritage research, up to its current state owes its success to the hardware and software tools made available through years of advancements in computing technology. These technologies have also in recent years contributed to new methods in archaeological interpretations which are largely based on the 'processual', and in recent times the 'experiential' aspect of it. In order to determine the environment of a prehistoric site or to pinpoint the likely settlement areas and subsistence of hunter-gatherers, a large body of research in landscape archaeology in particular, has depended on the use of GIS and automated systems for determining distributions of woodland vegetation on different spatial and temporal scales. GIS although useful, is fraught with limitations, and the model used for determining the distribution of vegetations does not reflect the ecology of its natural counterpart, therefore inconsistencies are found in predictions of differing models. Although i3D technologies have evolved in recent years to become both affordable and accessible, conventional methods in the interpretation of prehistoric landscapes or the prediction of current or future 'natural potential vegetation' via GIS, remained largely a process of assessing visual patterns in statistical visuals of two-dimensional space. Past research in landscape archaeology related to vegetation modelling therefore, requires further work as far as the 'processual' and 'experiential' aspect of archaeological interpretation is concerned.

The culmination of research efforts in computer graphics and VR over the years have addressed issues relating to various aspects of information visualisation, namely the interactivity and dynamics of visual representation of simulated data, enabling researchers to interact with data in 3D space by 'being there', thus augmenting the real-time experience and, it is claimed, the 'believability'. These technologies have been further developed through the gaming industry to become available and inexpensive. What is required is a bridge for connecting the 'processual' and the 'experiential'. A survey of research related to vegetation modelling (2.4) yielded partial models and approaches, many of which attempted at mimicking a natural look rather than realistic simulations.

The research reported in this thesis has investigated a new approach for modelling vegetation for reconstructing the Shotton river valley, integrating the field of Artificial Life with Virtual Environments for assisting the exploration and interpretation of the ancient landscape. In Chapter 2 of the thesis, relevant information relating to archaeological perception of the regions surrounding the river valley was collected. This, together with archaeological studies of the Mesolithic climate and environment, cultures, economy and subsistence, and vegetation types has produced an early digital perception of the landscape in the years 10,000 to 7,000bp before the flooding of the North Sea. The virtual reconstruction work investigates the processes required to convert the seismic dataset into an optimised polygon format suitable for interactive 3D. Various techniques for simulating artificial nature were assessed and applied onto the digital terrain, resulting in high quality digital images and animation. The reconstruction has, throughout the first half of 2004, been featured in over 30 printed media, broadcast media, websites, newswires and international media (See Appendix C). Four categories of Virtual Environments and interactive 3D have also been explored [337] (see 3.4) to determine its suitability as a tool for archaeological investigation and interpretation when the Artificial Life-based vegetation has been modelled.

Following the technical investigation into the feasibility of reconstructing a virtual Mesolithic landscape, new models incorporating Artificial Life-based vegetation and its ecology were researched and novel methods were developed [316, 338], also (Chapter 4). It was found in the research that in order for vegetation life-cycle to be appropriately synthesised and properly simulated, a unique engine incorporating the novel Artificial Life framework is required. Hence, the design and implementation of the *SeederEngine* architecture. The software architecture in its entirety integrates mathematical models and algorithmic formula for synthesising behaviours of vegetation. It also encompasses techniques for efficient description of generic vegetation, new optimisation algorithms for static Artificial Life, interactive 3D visualisation, and a unique Virtual Environment that could simulate both global and local ecological conditions with long term effects such as environmental changes and species migration. The research conducted has so far contributed to scientific knowledge in various fields of publications (See list of publications in the appendix). In chapter 5, experiments were conducted on the framework. In the experiments, characteristics known to occur in the interaction of vegetation communities and the effects of environmental changes were observed. Such correlations [317, 338, 339] between the artificial and the natural demonstrated the feasibility of using the model for reconstructing ancient landscapes.

Chapter 6 introduces a compressed simulation concept for optimising the speed and efficiency of the simulation. Comparisons with normal simulations showed relatively similar patterns of growth. The method is then applied into segments of the Shotton River Valley. Later, the distribution and characteristics of vegetation growth were reproduced in *CryTek*'s *CryEngine*™. A review of the growth segments by the archaeological team belonging to this collaborative project revealed a likely settlement area. Based on the study, Mesolithic artefacts and houses constructed in Chapter 3 were added onto the terrain so that the experiential aspect can be further enhanced. As Artificial Life-based plants are grown in more segments in future research, routes of travel paths of past hunter-gatherers could be traced, which could eventually reveal mysteries and lead to answers of the hidden past.

7.2. Discussions

The research has so far contributed to the field of Artificial Life-based vegetation modelling for reconstructing archaeological landscapes. As demonstrated in the work presented in this thesis, the fusion of virtual reality and Artificial Life can bring a Virtual Heritage reconstruction to a higher level of interactivity, providing a richer, evolvable content for public access and education, and as an enhanced 3D landscape reconstruction tool for archaeological exploration and interpretation. This section relates the outcome of the investigation to the research questions presented at the end of Chapter 1.

The goal of Virtual Heritage is to restore, preserve, and recreate artefacts in order to educate the general public regarding its values. Two fundamental requirements can be identified in this context – 1) the historical accuracy of the reconstruction related to a natural heritage site such as the Shotton River Valley and 2) the publishing of interactive media related to the reconstruction. In order to answer the former question, a survey of relevant modelling techniques was conducted. It was realised that techniques in vegetation modelling for determining their patterns of distribution in landscapes using GIS systems has been a topic of continual research since the last decade. The techniques evaluated in prominent works involved various levels of complexity. The techniques could be as simple as a rule-based system automating placements of vegetation to more complex algorithms in the field of AI. Nevertheless, assessments of these systems have shown various limitations and contrasting comparisons among the more prominent techniques. Others have implemented fractals and branching algorithms for describing plant structures, yet the sensory mechanisms in such systems are too resource-intensive for reconstructing large spatial-temporal landscapes. Vegetation modelling in the emerging field of Artificial Life is rare, and the few examples found were either partial or unrealistic as far as plant ecology is concerned. However, concepts and techniques discovered in AI, alife, and CAS could be integrated and further developed for modelling vegetation. The fusion of these methods, previously unrealised has been thoroughly researched and presented in Chapter 4. On the question of interactive media, via observations and actual implementations, it is clear that various PC and web-based interactive 3D media can effectively address the need of both the modelling and visualisation aspect of a Virtual Heritage site. On the question of whether the 'processual' and the 'experiential' aspect of archaeological reconstructions of landscape should be a separate procedure, provided that the computer at hand is sufficiently powerful, and that the optimisation algorithm for both Artificial Life interaction and visualisation is well developed, it need not be a separate procedure. However, to simulate hundreds of thousands of interacting plants in parallel requires huge amount of resources. An effective optimisation was developed in Chapter 4 to address this problem. Even so, the simulation speed can be greatly affected when plants started producing thousands of offspring over many generations.

Past vegetation modelling techniques for reconstructing landscapes depended heavily upon GIS-based systems. Although GIS systems could not properly address issues related to temporal analysis, 3D analysis, and the accuracy of the represented model, the lack of available tools has resulted in its widespread dependence as seen in the majority of landscape archaeology projects. To address the lack, *SeederEngine* was developed. The element of time was introduced as a fundamental core of the engine and as part of the interactive feature. The engine also supports via Microsoft's DirectX, a 3D environment capable of supporting 3D terrains, vegetations, and artefacts. By using the engine as a time-based 3D Virtual Environment, the lack can be resolved. However, since polygon-based 3D geometry is resource-intensive and an optimised 3D terrain necessarily reduces the number of polygons, the accuracy of the model could be compromised. Unless computational resources are unlimited, the polygons describing a terrain may not entirely represent a real world surface.

Past research in landscape archaeology uses the top-down approach in modelling the species distribution of plants across a terrain. Including AI, many systems using the top-down approach have failed to live up to expectations. Is the concept of the bottom-up approach studied in CAS and the synthesis of life in alife a superior model? In Chapter 2, a look at alife research in the past have shown that simple rules distilled from observations of biological systems and its interaction between similar and dissimilar entities can generate complex behaviours. Studies in complex systems have also shown that the concept of emergence reflects many naturally occurring phenomena. The Artificial Life model developed in Chapter 4 and verified in Chapter 5 has also demonstrated correlations between the alife-based plants and its natural counterpart. In such an approach, simple rules distilled from observations of natural vegetations described as equations and algorithms (Chapter 4) are the only components necessary for mimicking its natural counterpart. For example, the adaptability measure developed in this research is sufficient for measuring all environmental parameters related to the well being of a plant. The reductionist approach in Artificial Life can be further investigated in future research.

It was realised early in the conceptual design stages that in an alife environment, there are bound to be large numbers of alife entities interacting with other entities, both accessing and competing for resources. Computing resources therefore will be an issue. A survey of optimisation techniques did not yield suitable algorithms for engaging the special needs of this project. The segmentation algorithm was therefore developed (4.2.5). A comparison of simulations showed that there is considerable improvement in simulation speed if the segmentation algorithm is applied. Although the efficiency of the algorithm has been verified, resource bottleneck could still be a problem in larger landscapes. Therefore, continual development is needed in this area.

The techniques developed in this research could become useful in areas related to the modelling of life, behavioural, and social systems in living entities. In many of these systems, entities have certain tolerances towards the surrounding conditions. For example, fish have full tolerance to submerged environments and zero tolerance on land. In contrast, land-based mammals subject to how long it can hold its breath have zero tolerance under water. An amphibian on the other hand possesses a balanced adaptability to both land and water. The adaptability measure can be used in this case. In behavioural and social systems for example, certain people have very little tolerance towards certain behaviours whereas others are broad and generous. The adaptability measure can be used for measuring behaviours in such studies. The Artificial Life measure can also be used for measuring the level of attraction of a male-female in the mating games of animal species.

The artificial-life based vegetation model and the *SeederEngine* Virtual Environment have also demonstrated its potential usefulness in areas related to vegetation modelling. These areas are forest planning, landscape architecture, and the study of plant ecology and evolution. Its use is also expected to benefit the generation of ever changing landscapes virtual worlds for the games and entertainment industries.

7.3. Contributions

This section lists the research contributions from this thesis.

7.3.1. Living Virtual Heritage

The project has so far contributed to Virtual Heritage research by introducing the concept of a 'living' Virtual Environment with living Artificial Life entities that follows biological life cycles. The research for reconstructing a submerged ancient landscape with Artificial Life-based vegetation has never been attempted before.

Initial work in the literature survey includes the categorisation of the processes and requirements involved in Virtual Heritage research. A survey of interactive media types used in Virtual Heritage projects revealed at least four levels of interactivity and their impacts on user participation. The lack in current Virtual Heritage projects has also been identified and strategies specific to reconstructing heritage sites was planned and carried out in the entirety of this research. The strategies involved are processes for creating a 'living' 3D world from seismic data sources, strategies for 3D modelling and virtual representations, techniques for creating digital nature, Artificial Life modelling and framework design, implementations of a 'living' interactive 3D environment, and reconstructions in games engine. For this purpose, a pipeline of tools for Virtual Heritage creation from knowledge acquisition to public dissemination has been drafted. In summary, the outcome of the research has benefited the field of Virtual Heritage in the following areas:

- Identifying the lack in current Virtual Heritage projects
- Identifying the processes and levels of interactivity required for a richer content in Virtual Heritage sites
- Identifying suitable interactive 3D environment for ancient landscape creation
- Designed and implemented the strategies for converting seismic datasets, 3D modelling and virtual representations, digital nature, growing virtual vegetation, and reconstructions in games engine

- The design and implementation of a pipeline of tools required for reconstructing a 'living' Virtual Heritage site
- A unique Artificial Life and Virtual Environment engine for reconstructing natural settings in lost landscapes

7.3.2. Virtual Environment and Ecosystem

This research has also contributed to the field of Virtual Environment and virtual ecosystems. The *SeederEngine*, a unique games engine designed and implemented in this project is the result of the study. The engine is unique in that it was built specifically for synthesising the lifecycle of plant life and its ecology. In the context of an artificial ecosystem, the engine supports an interactive interface for real-time settings of environmental variables affecting Artificial Life entities in real-time. The engine also supports a five level interpolated vegetation representation and generic Artificial Life vegetation behaviours. Important features for determining vegetation distribution in ancient landscapes includes plant migration settings, large-timescale temperature variations, local to global environmental conditions, optimisation of Artificial Life entity interaction, ground info such as soil acidity, depth, texture, slope, and generic conditions describable with base maps. The engine can be used for studying the interaction of plant life and the evolution of plant life. It can also be extended to include other life forms.

7.3.3. Artificial Life of Plants and Plant Ecology

The lack in past research on vegetation modelling prompted the investigation for new and better approaches. The evaluation of past models found that certain fundamental principles required to properly synthesis behaviours of plant species were found to be either partial or lacking. It is discovered that no single system mentioned in the survey (2.4) collectively tackle these issues and therefore could not have been sufficiently accurate for plant synthesis. New models developed in Chapter 4 have since addressed issues related to modelling Artificial Life of plants and its ecology. The major part of this research is a direct contribution to Artificial Life modelling and plant ecology. The research has also provided new approaches related to modelling vegetation distribution on large landscapes.

7.3.4. Interaction Optimisation for Artificial Life Forms

An optimisation technique has been developed, experimented with, verified, and applied throughout the simulation exercises in this thesis. Comparisons of simulation with the segmentation algorithm applied showed a significant increase in speed in all simulations. The technique segments a virtual terrain so that vegetations in a fixed location senses and interacts with plants at proximity. The technique can be extended to include mobile Artificial Life and will be a research topic in future work.

7.3.5. Landscape Archaeological Reconstructions

Predictions of large-scale distribution of woodland types and forest succession models in archaeology uses simple techniques as compared to vegetation modelling using agent-based approaches (described in 2.4). These approaches are mainly hosted on a GIS. A survey revealed that GIS although useful, is fraught with limitations. Furthermore, conventional methods using GIS remained largely a process of assessing visual patterns in statistical visuals of two-dimensional space. This together with the limitations in the model has failed to live up to the 'processual' and 'experiential' aspect of archaeological interpretations. The development of *SeederEngine* and its associated Artificial Life and Virtual Environment have, to a certain extent resolved issues considered lacking by providing a foundation for constructing a '3D GIS' integrated with the new science of Artificial Life.

7.4. Problems and Limitations

Despite the continual development of the model and the engines supporting it right up to the time limit allocated for this research, limitations still exist. Certain problems relate to the capability of the software engine, other limitations are due to the input of data. Features deemed unnecessary such as visualisation capability of the software architecture could also be enhanced with further developments.

7.4.1. Visualisation

At the time of development and experimentations, visualisation in the *SeederEngine* viewport is kept to a minimum so that resources could be freed for computations of Artificial Life algorithms. Except for culling of polygon back faces, no other graphics optimisation techniques were applied. In future work, vertex processing techniques such as controlling the LOD with progressive mesh could be applied so that objects in the far plane are drawn with fewer polygons than is necessary. Shaders could also be applied for better rendering quality during simulation.

7.4.2. Modelling Accuracy Depending on Input Parameters

The accuracy of any scientific model is dependent on its input parameters. At this stage, except for the topology of the Mesolithic landscape, the environmental parameters of the Shotton river valley simulation are based archaeological studies of nearby regions surrounding the submerged landscape. Although a significant amount of work has been done on virtual reconstruction, modelling and the verifying of the Artificial Life model in various settings, knowledge of the actual seabed samples of this collaborative project between the Institute of Archaeology and Antiquity (IAA), the School of Geography, Earth, and Environmental Sciences (GEES) is still being collected. As information from the landscape is gradually being assembled, more accurate parameters can be fed into the Artificial Life model, thereby creating a more accurate model of the river valley.

7.4.3. Algorithm Optimisation

Although the segmentation algorithm, an optimisation technique developed and applied throughout this research has significantly increased the speed in all simulations, it can become ineffective as the amount of vegetation is further increased. As such, new optimisation techniques should be investigated.

7.5. Future Work

Continual research is necessary for refining the Artificial Life model and for improving aspects of the simulation environment. This section lists the various areas for potential future research work

7.5.1. Virtual Environment

The environmental parameters used in this research are presets based on Mesolithic settings. An extension can be made available on the software architecture so that live stream of current weather conditions can be fed into the system. The stream can then be processed based on a Knowledge Base storing Mesolithic settings so that environmental parameters can be increased or decreased accordingly. The Knowledge Base can also include Palaeolithic, Neolithic, Bronze Age, and other archaeological periods of time as a target area of study.

A highly causative interactive environment can also be introduced for allowing user interaction with natural calamities. For example, users could increase the temperature in the environment that will lead to a simulated glacial melting, causing the sea level to rise. The event and response of living entities could then be recorded for study.

7.5.2. Usability Testing

Usability studies, including the cataloguing of user feedback relating to content, interaction styles and interactive technologies are necessary for any software tools to become useful to their targeted audiences. In the present research, the usability situation is complex, as the results of this work, if taken further (for example, as part of the Virtual Scylla Project), will need to be made accessible to a range of end users, from marine biologists to engineers, and from wreck safety specialists to schoolchildren – each group having different requirements and expectations with regard to the interactive 3D content and the underpinning science. The *SeederEngine* and *SeederManager* developed in the research presented here were used extensively by the author in various experimentations in Chapters 4, 5, and 6. The tool has also been exposed to Geoarchaeologists and Palaeo-environmentalists, just two of the anticipated end user groups of researchers. However, no usability studies were conducted due to the boundary of the scope of research and the limits of time allocated for the work presented in this thesis. Future work should include the evaluation of the tools developed in this research for identifying not only usability issues related to human-centred design, but also the quality, completeness, and security of the software before deploying the package to the target audiences. Such an evaluation would include interaction design to counter problems such as user frustration and productivity, and may even capture user satisfaction of the software. In this context, Donald Norman's research [348, 349] related to mental models, conceptual models, affordances, and constraints could be applied to the design of the 2D user interfaces. Shneiderman's [350] concept on direct-manipulation interfaces could also be applied here and evaluated with his thoughts on expert reviews, usability testing, surveys and continuing assessments to the design of the interface. Studies related to interaction design within the 3D Virtual Environment such as Mine's [93] research could be useful, and, when necessary, Bowman's [94] research for common tasks in immersive Virtual Environments can be applied.

From the standpoint of a general population usability evaluation, adopting the Whitney Quesenbery "5 Es" approach to context-specific usability and user experience [340] would be a good, generic place to start in this instance:

- Effective: How completely and accurately the task or experience is completed or goals reached (the task here can be a range of activities – how well archaeologists can datamine or "drill-down" through the graphical interface to extract key scientific datasets, or how schoolchildren navigate the Shotton environs, searching for evidence to support their history project),
- Efficient: How quickly the task can be completed (not always an important issue in i3D applications),
- Engaging: How well the interface draws the user into the interaction (i.e. engages or immerses them) and how pleasant and satisfying it is to use,
- Error Tolerant: How well the task and interface design prevents errors and can help the user recover from mistakes that may occur,

- Easy to Learn: How well the task supports both the initial orientation and continued learning throughout the complete lifetime of use.

(Adapted from www.wqusability.com)

Appropriateness – in interactive 3D issues such as content, interactive technologies, sensory and behavioural fidelity – is an important issue in the design of VEs and Serious Gaming applications. The RATaC methodology (Rapid Assessment of Tasks and Context) can be used for evaluating the appropriate fidelity in the combination of software and hardware technologies. According to Stone [341], "Attention is now turning to more human-centred issues, focusing on appropriate content, sensory and functional fidelity, interaction style and the need for specialised display and control peripherals. Based on over a decade of research and development, the RATaC methodology has been designed to overcome some of the logistical, timing and financial restrictions faced by human factors specialists in trying to capture – during live, in-the-field, or operational assessment sessions with actual end users – the key components of training scenarios for the purposes of defining the scope of TBT (Technology-Based Training) solutions, particularly those based on i3D (e.g. VR or serious games)".

7.5.3. Graphics Engine

There are many potential areas for future work on the *SeederEngine*. Three main areas requiring future developments are the graphics rendering quality, the Scene Editor and graphing utilities, and optimisation algorithms for rendering and entity interaction. The current rendering quality is at a minimum but shaders can be included for enhancing the visualisation aspect of the simulation. A Scene Editor incorporating better user interfaces for preliminary settings, and a preview of landscape and 3D objects could be developed. A customisable graphing utility connecting various aspects related to studies on Artificial Life can also be included so that population densities and entity behaviours can be analysed with ease.

7.5.4. Reductionist Artificial Life

Currently, each Artificial Life entity possesses at least 30 variables out of which 40% of it is related to Artificial Life behaviours and the rest to DirectX visualisation. Variables tend to increase the usage of computing resources therefore, the less of it the better. Future work should look at a minimalist Artificial Life algorithm approach. Experiments can be conducted to determine the least amount of variables and rules necessary for synthesising the same behaviour of life witnessed in this research. If successful, the study should considerably reduce the usage of huge computing resources.

7.5.5. Evolution and Adaptation in Vegetation Artificial Life

The Artificial Life entity in this research reproduces asexually (cloning). Although sexual reproduction and genetic algorithms are possible using the XML genes developed in Chapter 4 and 5, it was not used as the Virtual Heritage project does not require it. In future research however, a pure Artificial Life study of plant ecology can be realised using the model. The future study should target areas related to the adaptation of plants so that their evolution can be understood more clearly. Such study can contribute to theoretical plant biology by locating ‘life-as-we-know-it’ within the larger picture of ‘life-as-it-could-be’.

7.5.6. Addition of Other Life Forms

Other life forms such as birds, animals, insects, and fishes should be introduced as part of the model affecting the Virtual Environment. The same research could be conducted to observe, generalise and distil behaviours of each category of life form.

7.5.7. Interaction Optimisation for Mobile Life Forms

The segmentation algorithm is designed for static life form such as plants. If mobile life forms are introduced as part of the model, new optimisation techniques will need to be developed.

7.6. Research Extension

Finally, a planned extension of the work described herein is to apply the Artificial Life algorithms and framework to the VE reconstruction of a more readily accessible underwater environment. Europe's first artificial reef (Figure 146), the ex-Royal Navy Batch 1 *Leander* Class Frigate HMS Scylla, scuttled in Whitsand Bay (near Plymouth, UK) now lies in 26-30m of water and to date, over 120 species of marine life have taken hold of the specially-prepared vessel. The extension will provide an ideal opportunity to simulate (and predict) the temporal course of the marine colonisation of the vessel (taking into consideration such factors as pollution and climate change).

Figure 146. Images of the scuttling of HMS Scylla – Europe's first artificial reef
(Sources of images: http://www.navyphotos.co.uk/scylla.htm)

Foundation work has been carried out for the future research extension reported here. On the 30^{th} of August 2006, the author and his PhD supervisor Prof. Robert J. Stone joined forces with the University of Plymouth, the National Marine Aquarium (NMA) and the Marine Biological

Association (MBA) in a new survey of the wreck. During the expedition, the NMA and MBA diving teams collected marine life samples and new photographic records from the reef onboard the *UK National*, a boat skippered by Prof. Richard Linford. Over 140 marine species have been recorded to date, including spiny starfish, pouting, queen scallops, sea squirts, various species of anemone and algae, mussels, starfish and sea urchins. The Birmingham team helped deployed the NMA's *VideoRay* remotely operated vehicle (ROV), which was used to gain access to areas of the ship where more detail was required for the ongoing reconstruction of the Virtual Scylla (Figure 147). Built by the author, the 3D model of the Scylla positioned within a games engine-based Virtual Environment, now awaits the population of artificial colonies of marine life.

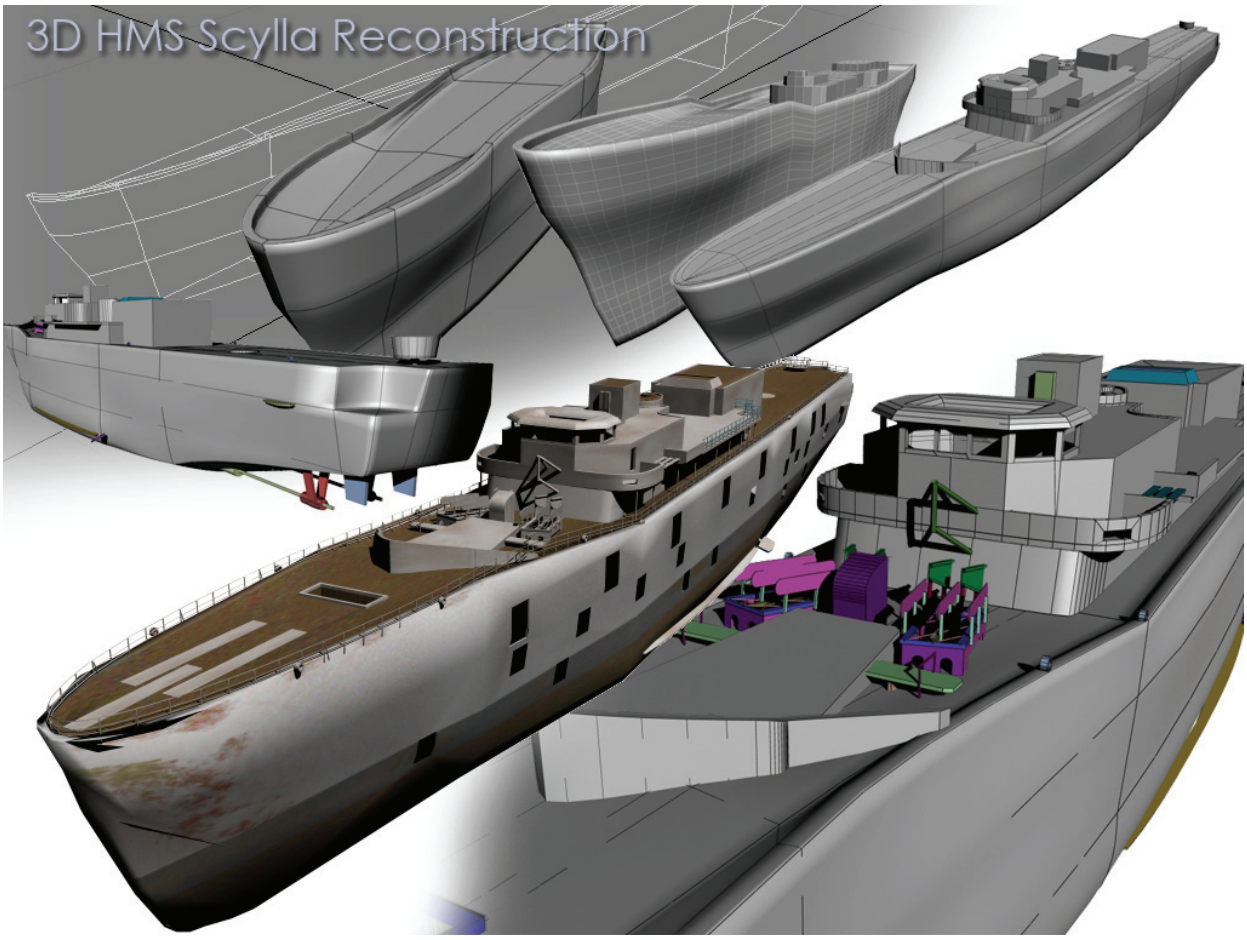


Figure 147. 3D Reconstruction of the HMS Scylla

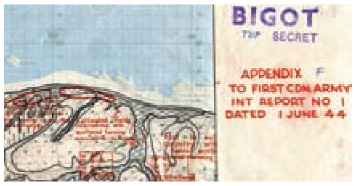
List of Publications

1. **Ch'ng E.** and Stone R.J., (2006) 3D Archaeological Reconstruction and Visualization: An Artificial Life Model for Determining Vegetation Dispersal Patterns in Ancient Landscapes. IEEE International Conference on Computer Graphics, Imaging and Vision, CGiV'06, 25-28 July 2006, Sydney, Australia.
2. Stone, R.J., Guest, R., **Ch'ng, E.**, McCririe, C., Collis, C., Mannur, R., & Rehmi, I. (2006). Serious Gaming Technologies Support Human Factors Investigations of Advanced Interfaces for Semi-Autonomous Vehicles. In Proceedings of Virtual Media for Military Applications; NATO RTA HFM-136 Workshop; US Military Academy; West Point, NY; 13-15 June.
3. **Ch'ng E.** and Stone R.J., (2006) Enhancing Virtual Reality with Artificial Life: Reconstructing a Flooded European Mesolithic Landscape. To appear in Presence Journal: Teleoperators and Virtual Environments, June 2006 Special Issue on Virtual Heritage, Presence 15 (3).
4. **Ch'ng, E**, Stone R.J., Arvanitis T.N., (2005) Evaluating Artificial Life-based Vegetation Dynamics in the Context of a Virtual Reality Representation of Ancient Landscapes. Virtual Systems and Multimedia, VSMM2005. Ghent, Belgium Oct 3-6, 2005.
5. **Ch'ng, E**, Stone R.J., Arvanitis T.N., (2005) A Virtual Reality Archaeological Framework for the Investigation and Interpretation of Ancient Landscapes. IASTED International Conference on Internet and Multimedia Systems and Applications, EuroIMSA2005. Grindelwald, Switzerland 21-23 February 2005.
6. **Ch'ng, E.**, Stone R.J., Arvanitis T.N., (2004) The Shotton River and Mesolithic Dwellings: Recreating the Past from Geo-Seismic Data Sources. The 5th International Symposium on Virtual Reality, Archaeology and Cultural Heritage, VAST (2004), in cooperation with ACM Siggraph and The Eurographics Association, 7-10 December 2004, Brussels, Belgium, pp. 125-133, 2004.

Note: Three additional journal papers are in review at the time of thesis submission.

Appendix A: Prof. Frederick William Shotton

Prof. Frederick William Shotton MBE FRS (1906-1990)



Prof. Fred Shotton was a renowned geologist who specialised in the study of Ice Age (Pleistocene) geology. A First Class Honours graduate from the University of Cambridge, he taught there and at the University of Birmingham between 1928 and 1940. During the Second World War, Shotton specialised in military geology, initially helping to locate water supplies for troops in North Africa and the Middle East. One of his most famous contributions to the War involved the generation of geological maps of the D-Day landing sites, pinpointing those regions that might be problematic for military vehicles. Following the war, Shotton became Professor of Geology at University of Sheffield, and from 1949 until his retirement in 1974 he was Lapworth Professor of Geology at the University of Birmingham. In the same spirit as present-day VR endeavours, Shotton pioneered *multidisciplinary* approaches to Pleistocene research, combining geology with archaeology and the study of the remains of flora and fauna mammals to create a multifaceted and information-rich reconstruction of past environments.

Appendix B: Genetic Blueprint of Vegetation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    <Sunlight Upper="0.93" Lower="0.09">0.45</Sunlight>
    <Temperature Upper="32" Lower="-4">20</Temperature>
    <Moisture Upper="0.89" Lower="0.1">0.21</Moisture>
    <Nutrient Upper="0.32" Lower="0.08">0.21</Nutrient>
    <Elevation Upper="656" Lower="-5">312</Elevation>
    <Space Upper="0.98" Lower="0.07">0.68</Space>
    <CO2 Upper="0.26" Lower="0.09">0.14</CO2>
    <SoilPh Upper="10" Lower="3">7</SoilPh>
    <SoilDepth Upper="1" Lower="0.05">0.25</SoilDepth>
    <Ground Upper="0.5" Lower="0">0.3</Ground>
  </Tolerance>
  <Reproduction>
    <Type>Sexual</Type>
    <DispersalType>Discharge</DispersalType>
    <SexualMaturityAge>0</SexualMaturityAge>
    <SeedCount>40</SeedCount>
    <AverageGerminationPercentage>20</AverageGerminationPercentage>
    <PollenReleaseDateStart>March</PollenReleaseDateStart>
    <PollenReleaseDateEnd>May</PollenReleaseDateEnd>
    <SeedingMonth>June</SeedingMonth>
  </Reproduction>
  <Germination>
    <DaysStart>30</DaysStart>
    <DaysEnd>90</DaysEnd>
    <MonthStart>February</MonthStart>
    <MonthEnd>October</MonthEnd>
    <Season>Spring</Season>
    <TemperatureLower>12</TemperatureLower>
    <TemperatureUpper>30</TemperatureUpper>
    <MoistureLower>0.33</MoistureLower>
    <MoistureUpper>0.92</MoistureUpper>
    <Soil>Clay</Soil>
  </Germination>
  <KnownDisease>
    <Disease>Root Disease</Disease>
  </KnownDisease>
</Plant>
```

```xml
<Plant>
  <Name>
    <Common>GrassHi</Common>
    <Scientific>Grass</Scientific>
  </Name>
  <Info>
    <MeasuringUnit>Metres</MeasuringUnit>
    <Memo>This is generic grass in medium height.</Memo>
  </Info>
  <File>
    <MeshDead>grassHiBunch.X</MeshDead>
    <MeshSeed>GrassSeed.X</MeshSeed>
    <MeshSeedling>grassHiBunch.X</MeshSeedling>
    <MeshYoung>grassHiBunch.X</MeshYoung>
    <MeshMature>grassHiBunch.X</MeshMature>
    <MeshOld>grassHiBunch.X</MeshOld>
  </File>
  <Growth>
    <MaximumAge>4</MaximumAge>
    <Type LeafType="Evergreen">Perrennials</Type>
    <BestSoil>Peat</BestSoil>
    <AcceptableSoil>Clay</AcceptableSoil>
    <MaxHeight>0.6</MaxHeight>
    <Canopy>0.6</Canopy>
    <LeafDensity>0.2</LeafDensity>
  </Growth>
  <Tolerance hardiness="0.3">
    <Sunlight Upper="1" Lower="0.35">0.6</Sunlight>
    <Temperature Upper="32" Lower="-5">20</Temperature>
    <Moisture Upper="0.95" Lower="0.3">0.5</Moisture>
    <Nutrient Upper="0.6" Lower="0.4">0.5</Nutrient>
    <Elevation Upper="1600" Lower="-10">50</Elevation>
    <Space Upper="0.6" Lower="0.98">0.7</Space>
    <CO2 Upper="0.6" Lower="0.4">0.5</CO2>
    <SoilPh Upper="10" Lower="3">7</SoilPh>
    <SoilDepth Upper="1" Lower="0.05">0.2</SoilDepth>
    <Ground Upper="0.76" Lower="0.09">0.2</Ground>
  </Tolerance>
  <Reproduction>
    <Type>ASexual</Type>
    <DispersalType>Discharge</DispersalType>
    <SexualMaturityAge>1</SexualMaturityAge>
    <SeedCount>20</SeedCount>
    <AverageGerminationPercentage>20</AverageGerminationPercentage>
    <PollenReleaseDateStart>May</PollenReleaseDateStart>
    <PollenReleaseDateEnd>June</PollenReleaseDateEnd>
    <SeedingMonth>June</SeedingMonth>
  </Reproduction>
  <Germination>
    <DaysStart>10</DaysStart>
    <DaysEnd>90</DaysEnd>
    <MonthStart>February</MonthStart>
    <MonthEnd>October</MonthEnd>
    <Season>Spring</Season>
    <TemperatureLower>12.6</TemperatureLower>
    <TemperatureUpper>33.9</TemperatureUpper>
    <MoistureLower>0.25</MoistureLower>
    <MoistureUpper>0.88</MoistureUpper>
    <Soil>Clay</Soil>
  </Germination>
  <KnownDisease>
    <Disease>Root Disease</Disease>
    <Disease>Root Decays</Disease>
    <Disease>Foliage Disease</Disease>
  </KnownDisease>
</Plant>
```

```xml
<Plant>
  <Name>
    <Common>GrassMid</Common>
    <Scientific>Grass</Scientific>
  </Name>
  <Info>
    <MeasuringUnit>Metres</MeasuringUnit>
    <Memo>This is generic grass in medium height.</Memo>
  </Info>
  <File>
    <MeshDead>grassMidBunch.X</MeshDead>
    <MeshSeed>GrassSeed.X</MeshSeed>
    <MeshSeedling>grassMidBunch.X</MeshSeedling>
    <MeshYoung>grassMidBunch.X</MeshYoung>
    <MeshMature>grassMidBunch.X</MeshMature>
    <MeshOld>grassMidBunch.X</MeshOld>
  </File>
  <Growth>
        <MaximumAge>3</MaximumAge>
    <Type LeafType="Evergreen">Perrennials</Type>
    <BestSoil>Peat</BestSoil>
    <AcceptableSoil>Clay</AcceptableSoil>
    <MaxHeight>0.3</MaxHeight>
    <Canopy>0.617</Canopy>
    <LeafDensity>0.2</LeafDensity>
  </Growth>
  <Tolerance hardiness="0.3">
    <Sunlight Upper="1" Lower="0.35">0.6</Sunlight>
    <Temperature Upper="32" Lower="-5">20</Temperature>
    <Moisture Upper="0.95" Lower="0.3">0.5</Moisture>
    <Nutrient Upper="0.6" Lower="0.4">0.5</Nutrient>
    <Elevation Upper="1600" Lower="-10">50</Elevation>
    <Space Upper="0.6" Lower="0.98">0.7</Space>
    <CO2 Upper="0.6" Lower="0.4">0.5</CO2>
    <SoilPh Upper="10" Lower="3">7</SoilPh>
    <SoilDepth Upper="1" Lower="0.05">0.2</SoilDepth>
    <Ground Upper="0.76" Lower="0.09">0.2</Ground>
  </Tolerance>
  <Reproduction>
    <Type>ASexual</Type>
    <DispersalType>Discharge</DispersalType>
    <SexualMaturityAge>1</SexualMaturityAge>
    <SeedCount>20</SeedCount>
    <AverageGerminationPercentage>20</AverageGerminationPercentage>
    <PollenReleaseDateStart>May</PollenReleaseDateStart>
    <PollenReleaseDateEnd>June</PollenReleaseDateEnd>
    <SeedingMonth>June</SeedingMonth>
  </Reproduction>
  <Germination>
    <DaysStart>10</DaysStart>
    <DaysEnd>90</DaysEnd>
    <MonthStart>February</MonthStart>
    <MonthEnd>October</MonthEnd>
    <Season>Spring</Season>
    <TemperatureLower>12.6</TemperatureLower>
    <TemperatureUpper>33.9</TemperatureUpper>
    <MoistureLower>0.25</MoistureLower>
    <MoistureUpper>0.88</MoistureUpper>
    <Soil>Clay</Soil>
  </Germination>
  <KnownDisease>
    <Disease>Root Disease</Disease>
    <Disease>Root Decays</Disease>
    <Disease>Foliage Disease</Disease>
  </KnownDisease>
</Plant>
```

```xml
<Plant>
  <Name>
    <Common>Hairy Hawkweed</Common>
    <Scientific>Hieracium gronovii L.</Scientific>
  </Name>
  <Info>
    <MeasuringUnit>Metres</MeasuringUnit>
    <Memo>Hairy Hawkweed</Memo>
  </Info>
  <File>
    <MeshDead>HairyHawkweedSeed.X</MeshDead>
    <MeshSeed>HairyHawkweedSeed.X</MeshSeed>
    <MeshSeedling>HairyHawkweed.X</MeshSeedling>
    <MeshYoung>HairyHawkweed.X</MeshYoung>
    <MeshMature>HairyHawkweed.X</MeshMature>
    <MeshOld>HairyHawkweed.X</MeshOld>
  </File>
  <Growth>
    <MaximumAge>5</MaximumAge>
    <Type LeafType="Herbaceous">Perrennials</Type>
    <BestSoil>Peat</BestSoil>
    <AcceptableSoil>Clay</AcceptableSoil>
    <MaxHeight>1.2</MaxHeight>
    <Canopy>0.8</Canopy>
    <LeafDensity>0.2</LeafDensity>
  </Growth>
  <Tolerance hardiness="0.3">
    <Sunlight Upper="0.99" Lower="0.4">0.46</Sunlight>
    <Temperature Upper="30" Lower="-4">20</Temperature>
    <Moisture Upper="0.92" Lower="0.14">0.3</Moisture>
    <Nutrient Upper="0.32" Lower="0.08">0.21</Nutrient>
    <Elevation Upper="2701" Lower="-7">746</Elevation>
    <Space Upper="0.92" Lower="0.07">0.62</Space>
    <CO2 Upper="0.26" Lower="0.09">0.14</CO2>
    <SoilPh Upper="10" Lower="3">7</SoilPh>
    <SoilDepth Upper="1" Lower="0.1">0.25</SoilDepth>
    <Ground Upper="0.56" Lower="0">0.3</Ground>
  </Tolerance>
  <Reproduction>
    <Type>Sexual</Type>
    <DispersalType>Discharge</DispersalType>
    <SexualMaturityAge>0</SexualMaturityAge>
    <SeedCount>40</SeedCount>
    <AverageGerminationPercentage>20</AverageGerminationPercentage>
    <PollenReleaseDateStart>March</PollenReleaseDateStart>
    <PollenReleaseDateEnd>May</PollenReleaseDateEnd>
    <SeedingMonth>June</SeedingMonth>
  </Reproduction>
  <Germination>
    <DaysStart>30</DaysStart>
    <DaysEnd>90</DaysEnd>
    <MonthStart>February</MonthStart>
    <MonthEnd>October</MonthEnd>
    <Season>Spring</Season>
    <TemperatureLower>12</TemperatureLower>
    <TemperatureUpper>24.4</TemperatureUpper>
    <MoistureLower>0.25</MoistureLower>
    <MoistureUpper>0.85</MoistureUpper>
    <Soil>Clay</Soil>
  </Germination>
  <KnownDisease>
    <Disease>Root Disease</Disease>
  </KnownDisease>
</Plant>
```

```xml
<Plant>
  <Name>
    <Common>Hazel</Common>
    <Scientific>Corylus Avellana</Scientific>
  </Name>
  <Info>
    <MeasuringUnit>Metres</MeasuringUnit>
    <Memo>This plant can be found over most of the British Isles and the European Mainland.</Memo>
  </Info>
  <File>
    <MeshDead>hazelDead.X</MeshDead>
    <MeshSeed>hazelNut.X</MeshSeed>
    <MeshSeedling>HazelSeedling.X</MeshSeedling>
    <MeshYoung>HazelYoung.X</MeshYoung>
    <MeshMature>hazelMature.X</MeshMature>
    <MeshOld>hazelOld.X</MeshOld>
  </File>
  <Growth>
    <MaximumAge>80</MaximumAge>
    <Type LeafType="Deciduous">Tree</Type>
    <BestSoil>Peat</BestSoil>
    <AcceptableSoil>Clay</AcceptableSoil>
    <MaxHeight>6</MaxHeight>
    <Canopy>8</Canopy>
    <LeafDensity>0.5</LeafDensity>
  </Growth>
  <Tolerance hardiness="0.55">
    <Sunlight Upper="0.98" Lower="0.27">0.4</Sunlight>
    <Temperature Upper="36" Lower="-6">20</Temperature>
    <Moisture Upper="0.56" Lower="0.25">0.47</Moisture>
    <Nutrient Upper="0.6" Lower="0.2">0.5</Nutrient>
    <Elevation Upper="600" Lower="-10">50</Elevation>
    <Space Upper="0.5" Lower="0.01">0.25</Space>
    <CO2 Upper="0.6" Lower="0.4">0.5</CO2>
    <SoilPh Upper="10" Lower="3">7</SoilPh>
    <SoilDepth Upper="1" Lower="0.2">0.4</SoilDepth>
    <Ground Upper="0.5" Lower="0">0.3</Ground>
  </Tolerance>
  <Reproduction>
    <Type>Sexual</Type>
    <DispersalType>Discharge</DispersalType>
    <SexualMaturityAge>10</SexualMaturityAge>
    <SeedCount>30</SeedCount>
    <AverageGerminationPercentage>20</AverageGerminationPercentage>
    <PollenReleaseDateStart>July</PollenReleaseDateStart>
    <PollenReleaseDateEnd>August</PollenReleaseDateEnd>
    <SeedingMonth>September</SeedingMonth>
  </Reproduction>
  <Germination>
    <DaysStart>30</DaysStart>
    <DaysEnd>180</DaysEnd>
    <MonthStart>April</MonthStart>
    <MonthEnd>August</MonthEnd>
    <Season>Autumn</Season>
    <TemperatureLower>14</TemperatureLower>
    <TemperatureUpper>24</TemperatureUpper>
    <MoistureLower>0.23</MoistureLower>
    <MoistureUpper>0.54</MoistureUpper>
    <Soil>Clay</Soil>
  </Germination>
  <KnownDisease>
    <Disease>Root Disease</Disease>
    <Disease>Root Decays</Disease>
    <Disease>Foliage Disease</Disease>
  </KnownDisease>
</Plant>
```

```xml
<Plant>
  <Name>
    <Common>Oak</Common>
    <Scientific>Quercus</Scientific>
  </Name>
  <Info>
    <MeasuringUnit>Metres</MeasuringUnit>
    <Memo>The Oak Tree</Memo>
  </Info>
  <File>
    <MeshDead>OakDead.X</MeshDead>
    <MeshSeed>OakAcorn.X</MeshSeed>
    <MeshSeedling>OakSeedling.X</MeshSeedling>
    <MeshYoung>OakYoung.X</MeshYoung>
    <MeshMature>OakMature.X</MeshMature>
    <MeshOld>OakOld.X</MeshOld>
  </File>
  <Growth>
    <MaximumAge>350</MaximumAge>
    <Type LeafType="Deciduous">Tree</Type>
    <BestSoil>Clay</BestSoil>
    <AcceptableSoil>Compost</AcceptableSoil>
    <MaxHeight>30</MaxHeight>
    <Canopy>35</Canopy>
    <LeafDensity>0.9</LeafDensity>
  </Growth>
  <Tolerance hardiness="0.3">
    <Sunlight Upper="1" Lower="0.43">0.69</Sunlight>
    <Temperature Upper="36" Lower="-7">20</Temperature>
    <Moisture Upper="0.66" Lower="0.32">0.45</Moisture>
    <Nutrient Upper="0.7" Lower="0.4">0.55</Nutrient>
    <Elevation Upper="450" Lower="-5">21</Elevation>
    <Space Upper="0.4" Lower="0.01">0.19</Space>
    <CO2 Upper="0.6" Lower="0.4">0.5</CO2>
    <SoilPh Upper="8" Lower="2">4.5</SoilPh>
    <SoilDepth Upper="1" Lower="0.3">0.45</SoilDepth>
    <Ground Upper="0.5" Lower="0">0.3</Ground>
  </Tolerance>
  <Reproduction>
    <Type>Sexual</Type>
    <DispersalType>Discharge</DispersalType>
    <SexualMaturityAge>20</SexualMaturityAge>
    <SeedCount>60</SeedCount>
    <AverageGerminationPercentage>20</AverageGerminationPercentage>
    <PollenReleaseDateStart>April</PollenReleaseDateStart>
    <PollenReleaseDateEnd>May</PollenReleaseDateEnd>
    <SeedingMonth>September</SeedingMonth>
  </Reproduction>
  <Germination>
    <DaysStart>30</DaysStart>
    <DaysEnd>365</DaysEnd>
    <MonthStart>March</MonthStart>
    <MonthEnd>August</MonthEnd>
    <Season>Autumn</Season>
    <TemperatureLower>12</TemperatureLower>
    <TemperatureUpper>25</TemperatureUpper>
    <MoistureLower>0.24</MoistureLower>
    <MoistureUpper>0.55</MoistureUpper>
    <Soil>Clay</Soil>
  </Germination>
  <KnownDisease>
    <Disease>Root Disease</Disease>
    <Disease>Root Decays</Disease>
    <Disease>Foliage Disease</Disease>
  </KnownDisease>
</Plant>
```

```xml
<Plant>
  <Name>
    <Common>Pine</Common>
    <Scientific>Pinus Sylvestris</Scientific>
  </Name>
  <Info>
    <MeasuringUnit>Metres</MeasuringUnit>
    <Memo>This plant grows well in high elevation in the North...</Memo>
  </Info>
  <File>
    <MeshDead>pineDead.X</MeshDead>
    <MeshSeed>pineTreeSeed.X</MeshSeed>
    <MeshSeedling>pineTreeSeedling.X</MeshSeedling>
    <MeshYoung>pineTreeYoung.X</MeshYoung>
    <MeshMature>pineTreeMature.X</MeshMature>
    <MeshOld>pineTreeOld.X</MeshOld>
  </File>
  <Growth>
    <MaximumAge>200</MaximumAge>
    <Type LeafType="Evergreen">Tree</Type>
    <BestSoil>Peat</BestSoil>
    <AcceptableSoil>Clay</AcceptableSoil>
    <MaxHeight>50</MaxHeight>
    <Canopy>17.112</Canopy>
    <LeafDensity>0.9</LeafDensity>
  </Growth>
  <Tolerance hardiness="0.3">
    <Sunlight Upper="0.99" Lower="0.42">0.6</Sunlight>
    <Temperature Upper="35" Lower="-20">9</Temperature>
    <Moisture Upper="0.58" Lower="0.2">0.55</Moisture>
    <Nutrient Upper="0.55" Lower="0.32">0.41</Nutrient>
    <Elevation Upper="2440" Lower="-3">750</Elevation>
    <Space Upper="0.78" Lower="0.1">0.32</Space>
    <CO2 Upper="0.6" Lower="0.4">0.5</CO2>
    <SoilPh Upper="8" Lower="3">6</SoilPh>
    <SoilDepth Upper="1" Lower="0.2">0.45</SoilDepth>
    <Ground Upper="0.7" Lower="0">0.3</Ground>
  </Tolerance>
  <Reproduction>
    <Type>Sexual</Type>
    <DispersalType>Discharge</DispersalType>
    <SexualMaturityAge>15</SexualMaturityAge>
    <SeedCount>120</SeedCount>
    <AverageGerminationPercentage>20</AverageGerminationPercentage>
    <PollenReleaseDateStart>July</PollenReleaseDateStart>
    <PollenReleaseDateEnd>August</PollenReleaseDateEnd>
    <SeedingMonth>September</SeedingMonth>
  </Reproduction>
  <Germination>
    <DaysStart>30</DaysStart>
    <DaysEnd>180</DaysEnd>
    <MonthStart>April</MonthStart>
    <MonthEnd>August</MonthEnd>
    <Season>Autumn</Season>
    <TemperatureLower>12</TemperatureLower>
    <TemperatureUpper>28</TemperatureUpper>
    <MoistureLower>0.23</MoistureLower>
    <MoistureUpper>0.6</MoistureUpper>
    <Soil>Clay</Soil>
  </Germination>
  <KnownDisease>
    <Disease>Root Decays</Disease>
    <Disease>Wound Decays</Disease>
  </KnownDisease>
</Plant>
```

```xml
<Plant>
  <Name>
    <Common>Stinging Nettle</Common>
    <Scientific>Urtica dioica</Scientific>
  </Name>
  <Info>
    <MeasuringUnit>Metres</MeasuringUnit>
    <Memo>Stinging Nettle</Memo>
  </Info>
  <File>
    <MeshDead>stingingnettleseed.X</MeshDead>
    <MeshSeed>stingingnettleseed.X</MeshSeed>
    <MeshSeedling>stingingnettle.X</MeshSeedling>
    <MeshYoung>stingingnettle.X</MeshYoung>
    <MeshMature>stingingnettle.X</MeshMature>
    <MeshOld>stingingnettle.X</MeshOld>
  </File>
  <Growth>
    <MaximumAge>5</MaximumAge>
    <Type LeafType="Herbaceous">Perrennials</Type>
    <BestSoil>Peat</BestSoil>
    <AcceptableSoil>Clay</AcceptableSoil>
    <MaxHeight>1.2</MaxHeight>
    <Canopy>0.8</Canopy>
    <LeafDensity>0.2</LeafDensity>
  </Growth>
  <Tolerance hardiness="0.3">
    <Sunlight Upper="0.99" Lower="0.4">0.46</Sunlight>
    <Temperature Upper="30" Lower="-5">20</Temperature>
    <Moisture Upper="0.92" Lower="0.14">0.3</Moisture>
    <Nutrient Upper="0.32" Lower="0.08">0.21</Nutrient>
    <Elevation Upper="2701" Lower="-7">746</Elevation>
    <Space Upper="0.92" Lower="0.07">0.62</Space>
    <CO2 Upper="0.26" Lower="0.09">0.14</CO2>
    <SoilPh Upper="10" Lower="3">7</SoilPh>
    <SoilDepth Upper="1" Lower="0.1">0.25</SoilDepth>
    <Ground Upper="0.56" Lower="0">0.3</Ground>
  </Tolerance>
  <Reproduction>
    <Type>Sexual</Type>
    <DispersalType>Discharge</DispersalType>
    <SexualMaturityAge>0</SexualMaturityAge>
    <SeedCount>40</SeedCount>
    <AverageGerminationPercentage>20</AverageGerminationPercentage>
    <PollenReleaseDateStart>March</PollenReleaseDateStart>
    <PollenReleaseDateEnd>May</PollenReleaseDateEnd>
    <SeedingMonth>June</SeedingMonth>
  </Reproduction>
  <Germination>
    <DaysStart>30</DaysStart>
    <DaysEnd>90</DaysEnd>
    <MonthStart>February</MonthStart>
    <MonthEnd>October</MonthEnd>
    <Season>Spring</Season>
    <TemperatureLower>12</TemperatureLower>
    <TemperatureUpper>24.4</TemperatureUpper>
    <MoistureLower>0.25</MoistureLower>
    <MoistureUpper>0.85</MoistureUpper>
    <Soil>Clay</Soil>
  </Germination>
  <KnownDisease>
    <Disease>Root Disease</Disease>
  </KnownDisease>
</Plant>
```

```xml
<Plant>
  <Name>
    <Common>Water Pepper</Common>
    <Scientific>Persicaria hydropiper</Scientific>
  </Name>
  <Info>
    <MeasuringUnit>Metres</MeasuringUnit>
    <Memo>The Family Cyperaceae, or the Sedge family, is a taxon of monocot flowering plants that
superficially resemble grasses or rushes.</Memo>
  </Info>
  <File>
    <MeshDead>WaterPepper.X</MeshDead>
    <MeshSeed>FernSpore.X</MeshSeed>
    <MeshSeedling>WaterPepper.X</MeshSeedling>
    <MeshYoung>WaterPepper.X</MeshYoung>
    <MeshMature>WaterPepper.X</MeshMature>
    <MeshOld>WaterPepper.X</MeshOld>
  </File>
  <Growth>
    <MaximumAge>4</MaximumAge>
    <Type LeafType="Herbaceous">Perrennials</Type>
    <BestSoil>Peat</BestSoil>
    <AcceptableSoil>Clay</AcceptableSoil>
    <MaxHeight>0.7</MaxHeight>
    <Canopy>0.35</Canopy>
    <LeafDensity>0.25</LeafDensity>
  </Growth>
  <Tolerance hardiness="0.3">
    <Sunlight Upper="0.98" Lower="0.3">0.55</Sunlight>
    <Temperature Upper="32" Lower="-4">20</Temperature>
    <Moisture Upper="0.97" Lower="0.39">0.75</Moisture>
    <Nutrient Upper="0.5" Lower="0.08">0.21</Nutrient>
    <Elevation Upper="400" Lower="0.01">212</Elevation>
    <Space Upper="0.8" Lower="0.07">0.4</Space>
    <CO2 Upper="0.26" Lower="0.09">0.14</CO2>
    <SoilPh Upper="10" Lower="3">7</SoilPh>
    <SoilDepth Upper="1" Lower="0.05">0.2</SoilDepth>
    <Ground Upper="0.56" Lower="0.09">0.2</Ground>
  </Tolerance>
  <Reproduction>
    <Type>Sexual</Type>
    <DispersalType>Discharge</DispersalType>
    <SexualMaturityAge>1</SexualMaturityAge>
    <SeedCount>50</SeedCount>
    <AverageGerminationPercentage>20</AverageGerminationPercentage>
    <PollenReleaseDateStart>March</PollenReleaseDateStart>
    <PollenReleaseDateEnd>May</PollenReleaseDateEnd>
    <SeedingMonth>June</SeedingMonth>
  </Reproduction>
  <Germination>
    <DaysStart>30</DaysStart>
    <DaysEnd>120</DaysEnd>
    <MonthStart>February</MonthStart>
    <MonthEnd>October</MonthEnd>
    <Season>Spring</Season>
    <TemperatureLower>12</TemperatureLower>
    <TemperatureUpper>25</TemperatureUpper>
    <MoistureLower>0.65</MoistureLower>
    <MoistureUpper>0.93</MoistureUpper>
    <Soil>Clay</Soil>
  </Germination>
  <KnownDisease>
    <Disease>Root Disease</Disease>
  </KnownDisease>
</Plant>
```

```xml
<Plant>
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    <Scientific>Salix</Scientific>
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America.</Memo>
  </Info>
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    <MeshSeed>WillowSeed.X</MeshSeed>
    <MeshSeedling>WillowSeedling.X</MeshSeedling>
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    <MeshMature>WillowMature.X</MeshMature>
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  </Growth>
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  </Germination>
  <KnownDisease>
    <Disease>Root Disease</Disease>
    <Disease>Root Decays</Disease>
    <Disease>Foliage Disease</Disease>
  </KnownDisease>
</Plant>
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Appendix C: Project Press Releases

Printed Media:

- Birmingham Evening Mail (13.02.04)
- Aberdeen Press & Journal Series (16.02.04)
- Birmingham Post (16.02.04)
- Daily Mirror (16.02.04)
- Dundee Courier & Advertiser Series (16.02.04)
- The Morning Star (16.02.04)
- The Northern Echo (16.02.04)
- The Scotsman (16.02.04)
- Scottish Daily Record (16.02.04)
- The Times (16.02.04)
- Wolverhampton Express and Star (16.02.04)
- Birmingham News (19.02.04)
- The Guardian (19.02.04)
- Solihull News (20.02.04)
- Isle of Man Examiner (24.02.04)
- Isle of Man Courier (26.02.04)

Broadcast Media:

- BBC Radio WM – Late Show (Vince Gaffney interviewed)

Websites and Newswires:

- English Heritage, Marine History Environment Protection: New research into marine evaluation and mitigation techniques. The Aggregate Levy Sustainability Fund (ALSF) Annual Report 2005-2006. (www.english-heritage.org.uk)
- Case Studies in Advanced ICT Methods. North Sea Palaeolandscapes 2006, (www.methodsnetwork.ac.uk)
- ahessc: North Sea Palaeolandscapes, 2006 (www.ahessc.ac.uk)
- Ananova (www.ananova.com – 16.02.04)
- Press Association (15.02.04)

- The Undoctored Past – journal of the School of Archaeology and Ancient History at the University of Leicester (www.undoctored.ac.uk)
- Forskning – Norwegian science news website (www.forskning.no – 19.03.04)
- Virtual Heritage (www.virtualheritage.org)
- Science Magazine Australia (www.sciencemag.org - 15.03.04)
- Newsblaster (www.newsblaster.cs.columbia.edu - 05.03.04)
- Science News Western Australia (www.scitech.org.au - July 2004)
- Nordsjöns förlorade kontinent (www.geologinsdag.nu - 17.03.04)
- Popular Mechanics (www.popularmechanics.com 2004)

International Media:

- Discover Magazine (USA)
- Kidsweek (Dutch newspaper for 10-15 years old – www.kidsweek.nl)
- Gazeta Wyborcza (Largest national Polish newspaper – www.gazeta.pl)
- Corriere della Sera (National Italian newspaper)
- Quo Magazine (Spanish scientific magazine)
- Science, Outsider
- Ingenioren (Danish science magazine and technology weekly magazine)
- London Press Service (promotes UK innovation overseas on behalf of the Foreign & Commonwealth Office)
- Maritimt Magasin (Norwegian magazine)
- Illustreret Videnskab (Illustrated Science Magazine – Copenhagen, Denmark)

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