Supplementary Material 1: Technical Report on the Development and Use of the Geovisualisation Tool for Invasive Species Management

Introduction

The Mitlenatch Island Visualisation tool (MIVis) is a realistic, first-person perspective geovisualisation tool that provides a comprehensive and immersive experience for users to visualise Mitlenatch Island Provincial Park, British Columbia, Canada. The tool allows users to experience the island from a first-person point of view and explore its landscapes. The primary focus of the tool is to visualise the impact of Himalayan blackberry on the island and to showcase the outcomes of different management strategies. By using interactive virtual environments, 3D models and realistic simulations, the tool provides a unique and interactive way to understand the relationships between the island's environment and the efforts to manage invasive species.

This technical report presents the design and development of MIVis. The tool was designed using a gaming software, Unity 3D (version 2020.1.9f1), with the capability of creating an open world environment. This software allows for a variety of elements to be incorporated, such as terrain, weather, and first-person character movement, and interaction. The tool is designed to provide interactive experience, where users can virtually freely explore Mitlenatch Island. Additional software like QGIS (version 13.16.10), GIMP, Adobe Photoshop, and SketchUp are used to prepare data for integration into Unity 3D. These additional software allow for more detailed design elements, creating a visually realistic virtual environment.

This report provides details on the study background, park management scenarios development, and design considerations. Additionally, this report provides an overview of the features and functionalities of the tool, interactive visualisations, and data presentation capabilities. The report consists of three main sections, each focusing on a specific aspect of the visualisation tool. The next section discusses the background of the project, the process of scenario creation, and the justifications for the chosen scenarios. The following section delves into the technical details of the tool's design, including the methodologies used and the tools and techniques involved. Finally, the last section outlines the user experience and interaction with the tool, as well as providing an overview of the features and functionalities.

Background and Scenario Creation

This section presents the background behind, and process of, selecting scenarios for the use in MIVis. This geovisualisation tool was built as part of a previous research project on visualising the sea level rise of the same study area (Newell et al., 2021). This work involved engagement and discussions with practitioners from BC Parks, it was discovered that prescribed burning was the intended management strategy for the island. The plan aimed to address invasive species, control tree and shrub growth, and promote the growth of native herbaceous plants. (Maslovat et al., 2019). To align this research with real-world issues and priorities, the issue of Himalayan blackberry management on the island was then selected as the focus of the geovisualisation tool. There was an existing method of controlling Himalayan blackberry, as well as maps indicating the locations of the monitoring plots. Additionally, a number of volunteers from the Mitlenatch Island Stewardship Team (MIST) who were engaged in controlling the Himalayan blackberry provided an opportunity to recruit these people to be our participants in this study.

Himalayan blackberry

The Himalayan blackberry (*Rubus armeniacus*) is a robust, semi-evergreen perennial shrub that is native to the Caucasus region of Eurasia (Caplan & Yeakley, 2016; Gaire et al., 2015). It was introduced to British Columbia (BC) in the 19th century as a berry crop and has since been considered an invasive species (Metro Vancouver, 2021). This species is recognisable for its large, woody canes and thorny branches, which can grow up to 3 metre in height and 6 to 12 metre in length (Gaire et al., 2015). It produces clusters of white or pink flowers, followed by juicy, sweet-tart berries that are enjoyed by both humans and wildlife (Gaire et al., 2015). Despite its appealing fruit, Himalayan Blackberry poses a problem as it can displace native vegetation, reduce habitat quality, and alter ecosystem processes (Metro Vancouver, 2021). Himalayan blackberry is difficult to control or eradicate because of its

adaptability and rapid reproduction (ISCBC, 2021; Soll, 2004). Once established, it competes with low stature native vegetation and can prevent the establishment of shade-intolerant trees, such as Douglas firs (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), and Oregon white oak (*Quercus garryana*), leading to the formation of permanent Himalayan blackberry thickets with few other vegetation present (Soll, 2004).

A database search of Himalayan blackberry was conducted using both the common name, 'Himalayan blackberry,' and its scientific name, *'Rubus armeniacus,'* to ensure comprehensive results. The search was performed using various scientific databases, such as Web of Science and Google Scholar, to identify relevant scientific publications and studies related to Himalayan blackberry. The search yielded 60 relevant articles published since 1991, with the majority being research articles, reviews, and conference proceedings related to plant science, ecology, and biodiversity conservation (Figure 5). These studies focused on investigating the impact of Himalayan blackberry on various ecosystems. Moreover, the available data on the effectiveness of fire as a management strategy for Himalayan blackberry were limited, with most studies investigating the short-term effects of single or multiple prescribed burnings (Fryer, 2021). In addition to the research papers, an informative document provided by BC Parks (Maslovat et al., 2019), which detailed the impact of the Himalayan blackberry on Mitlenatch Island, was used to develop MIVis.
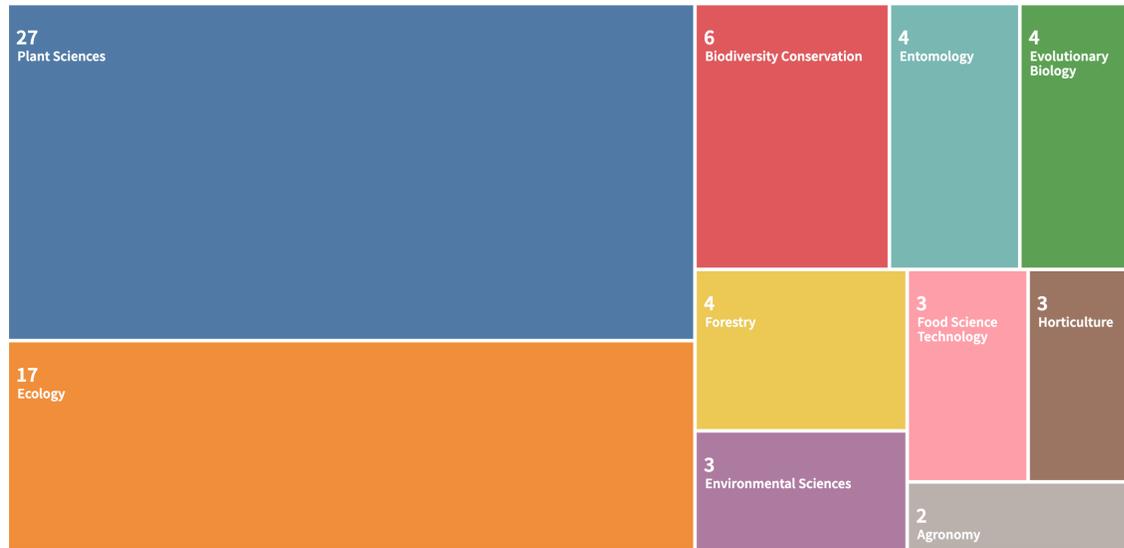
Figure 1: Results of the Web of Science database.

Himalayan blackberry management scenarios

The management strategies scenarios included in MIVis were based on both the existing method used by volunteers and other strategies of interest to stakeholders. The scenarios are supported by a review of available literature and information pertaining to the subject. The control method of Himalayan blackberry on Mitlenatch Island was hand cutting, which was mainly done by volunteers who cut the canes at the base near the roots and then recut them at the ground level every two weeks during the growing period (Maslovat et al., 2019). The method of controlling Himalayan blackberry was changed from hand cutting to hand-pulling because of a lack of literature on studies on the effectiveness of hand cutting, and hand-pulling was the closest alternative available. Additionally, mowing was included as it was another common method in Himalayan blackberry management strategy. Combining different treatments is a common strategy for controlling Himalayan blackberry, as it can improve treatment effectiveness and increase the likelihood of achieving management objectives (Ensley, 2015); a combined approach of mowing and prescribed burning was included in MIVis.

There is no one-size-fits-all solution for determining the most effective approach. The optimal management practice varies depending on the situation, objectives, financial resources, and the willingness or capacity to use herbicides (Soll, 2004). By presenting these scenarios in the visualisation tool, practitioners can gain a better understanding of the potential outcomes of each strategy and make informed decisions about their parks management practices. This approach helps to clearly demonstrate the effectiveness of different treatment methods in controlling the growth of Himalayan blackberry and promoting the growth of desired native species. Through the literature review in biological invasion research, we found that researchers frequently compare changes in plant density and herbaceous counts before and after management strategies (Clark & Wilson, 2001; Nuckols et al., 2011; Ensley, 2015; Chow, 2018). Using this as the starting point, the changes in plant density have been used as a reference to create a visualisation of the difference between the before and after treatment scenarios (Figure 6). The three factors for understanding invasive species management, which were outlined by Pearson and Ortega (2019), were included in MIVis. These factors are the impact of invaders, the side effects of management strategies, and the potential for secondary invasions. In summary, the main objective of MIVis is to offer a visualisation of the Himalayan blackberry, including scenarios of unmanaged growth and four management strategies: hand-pulling, mowing, prescribed burning, and a combination of mowing and prescribed burning. Each management scenario contains three stages to show the 'Current' stage, 'After treatment' stage and 'After one growing season' stage.
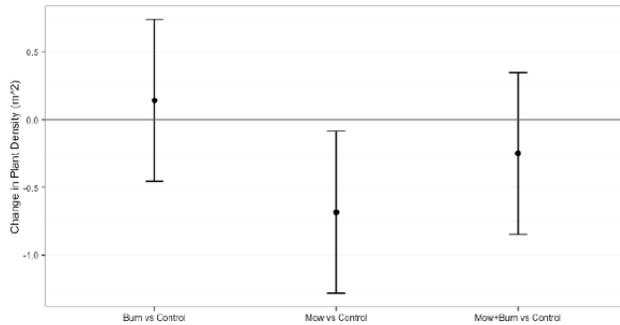
Figure 2.4 Plot of the estimated differences in mean change in average plant densities for each treatment compared to the control. Mean for the control is shown as a line set at 0. Bars represent FDR-adjusted 90% confidence intervals of the estimates.

A
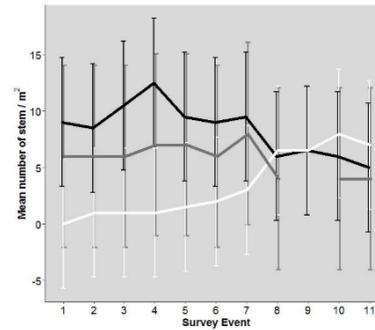
Figure 4 – Mean number of stems in the mowing (n=1), hand removal (n=2), and control (n=2) treatments from survey event 1 to 11. The grey line represents mowing treatments. The white line represents hand removal treatments. The black line represents control treatments. The whiskers indicate 95% confidence intervals (CIs).

B

Figure 2: Reference used for before and after treatment. Differences in average plant density, results from Ensley, 2015 (A); Difference in average plant stems results from Chow, 2018 (B).

Scenario 1: Hand-pulling

Hand-pulling is a popular strategy used to remove the entire plant, including the stems, root crowns, and fragments, to prevent regrowth (Soll, 2004). Although it is a laborious and time-consuming task, hand-pulling allows users to selectively remove Himalayan blackberry plants, leaving behind desired native species, allowing them to grow without competing with the invasive species (Metro Vancouver, 2021).

In the 'After treatment' stage, the presence of desirable or native species were shown in the treatment area, with visible ground disturbance resulting from the removal of Himalayan blackberries. However, even with the best effort, it is impossible to completely remove all parts of the plant, and regrowth is inevitable (Gaire et al., 2015). Additionally, bare soil caused by the treatment makes it susceptible to secondary invaders. Each management scenario contains three stages to demonstrate the impact of the four management strategies on the environment. These stages include the 'Current' stage, which represents the state of the area before any management interventions have taken place. The 'After treatment' stage represents the state of the area immediately after the management has been implemented. Finally, the 'After one growing season' stage shows the changes that have occurred in the

area after a full growing season. By visualising the changes between these stages, users can gain insights into how each management scenario affects the environment.

Scenario 2: Mowing

Mowing is an inexpensive approach that removes above ground vegetation using a mower (Soll, 2004). This treatment exhausts the reserve food supply in the roots and minimises the regrowth rate (ISCBC, 2014). Using a mower removes all the aboveground vegetation, including desirable or native plants (ISCBC, 2014). In the 'After treatment' stage, users can observe a disrupted soil surface with visible plant stems left on the mowed area (Bennett, 2007). Mowing treatment focuses on reducing the canes but does little to mitigate growth and spread belowground (Soll, 2004). As mowing only removes the aboveground plants, this can lead to the invasion of other weeds (Bennett, 2007).

In the 'After one growing season' stage, users can observe the Himalayan blackberry regrowth is marginally diminished compared to the 'Current' stage, however, it is still more compared to hand-pulled scenario. The visibility of desired native herbaceous species is also lower in the aftermath of the mowing treatment as it may have caused their elimination. Additionally, a few secondary invasive species have established themselves in the area.

Scenario 3: Prescribed burning

Prescribed burning is a method that utilises fire to eliminate the above-ground growth of woody species, such as Himalayan blackberry, to create space for the growth of herbaceous vegetation (Soll, 2004). This technique has a long history on the island and has been used to suppress woody vegetation, promote herbaceous species, and encourage seed production and seedling recruitment, including Saskatoon berry (Maslovat et al., 2019). Although fire kills most of the above-ground plants, some species, including Himalayan blackberry, may survive the burn (Soll, 2004).

The 'After treatment' stage shows the burnt plants and ground caused by the fire treatment, with some plants managing to escape the fire. The morphological and regeneration characteristics of Himalayan blackberry enable it to regenerate after a fire, as the heat can increase the germination rate of its seeds by cracking their hard seed coat (Fryer, 2021). After a single burn, the plant abundance either remains the same as before or increases (Bennett, 2006). However, the removal of above-ground plants may lead to the establishment of other invasive weeds, such as velvetgrass (*Holcus lanatus*), which thrive after a fire treatment. In the 'After one growing season' stage, the Himalayan blackberry is more visible than in the 'Current' stage (pre-treatment), and secondary invaders have established themselves in the treated area.

Scenario 4: Mowing and Prescribed Burning

Combining various management strategies can improve the effectiveness and probability of managing Himalayan blackberries (Bennett, 2007). In situations where there is limited or no ground cover apart from the invasive species, partial mowing or chopping of the canes may be necessary to facilitate the spread of fire (Soll, 2004). Mowing exhausts the soil seed bank and underground food reserve (Soll, 2004), while fire suppresses the growth of other woody vegetation and promotes the growth of fire-tolerant vegetation (Fryer, 2021). After mowing, fire treatment should follow immediately. After one treatment, a combined mowing and burning may not significantly reduce Himalayan blackberry spread. A combination of control strategies is recommended for the long-term control of Himalayan blackberries (Bennett, 2007). However, few studies have assessed the long-term response of Himalayan blackberries to a combination of control strategies. Constant monitoring of the area and changing treatment plans are highly recommended.

In the 'After treatment' stage, remnants of the mowed stems can be observed along with burnt stems and scorched ground resulting from the fire treatment. After a single treatment, a combined

mowing and burning strategy may not significantly reduce Himalayan blackberry spread (Soll, 2004). 'After one growing season' stage depicts a slight reduction in the regrowth of blackberry compared to the Current Scenario, and there is less visibility of the desired/native herbaceous species. The mowing treatment used could have led to the killing of these species. Additionally, a few secondary invasive species have established themselves in the area.

Building the Geovisualisation

This section provides detailed information on the design process and the technical specifications that went into creating the visualisation tool. A 3D geovisualisation of an island shows a virtual representation of the physical features and geography of the island. This includes the elevations and topographical data, as well as vegetation and its unique characteristics. With a 3D interface, the user can interact with the visualisation, explore different areas of the island, and gain insights into how various factors interact with and influence one another.

The development process used a combination of QGIS, Photoshop/GIMP, SketchUp, and Unity 3D. QGIS (version 13.16.10), which is a free and open-source GIS software, was used to prepare the spatial data (QGIS, n.d.). It has the advantage of preserving the spatial integrity of the data and can perform the same tasks as another commonly used GIS software, ArcGIS. Adobe Photoshop, and GIMP were utilised to create realistic textures as it enabled us to process and manipulate images and graphics to attain the required visual representation. SketchUp was used to build objects and structures that were unique to the island, such as the volunteer hut. The virtual environment was built using Unity 3D, a gaming open-world environment platform.

Unity 3D terminology

This section presents the terminology that is relevant to this research and used in Unity 3D projects. Firstly, the commonly used features in Unity are the GameObjects, which are objects that form the basis for a wide range of functionalities and can be used to build complex and engaging virtual environments. Various types of GameObjects exist within Unity, but for this particular application, only a select few common GameObjects are utilised.

- 3D GameObjects: These are the most common type of GameObjects used to build the game world. They can be empty or contain one or more components that define their behaviour.

- Cameras: Cameras are GameObjects that define the view of the player. They can be used to create different perspectives, such as first-person or third-person views.

- Audio Sources: Audio Sources are GameObjects that emit sound effects or music. They can be used to create a more immersive game experience.

- User Interface (UI) Elements: UI Elements are GameObjects that create the interface for the player to interact with the game, such as buttons, sliders, and menus.

In summary, GameObjects are used to represent elements that need to be manipulated or interacted with in the geovisualisation tool. A 3D GameObject can be used to represent a terrain object in Unity, such as a rock or tree that is part of the terrain. Terrain details are two-dimensional elements that are placed orthogonally to terrain surfaces within a 3D GameObject. They always face the viewer, regardless of the viewing angle, and are utilised to enhance the visual complexity and realism of a terrain surface. This method eliminates the need to create and manage a large number of individual GameObjects.

In Unity, a 2D scene refers to a two-dimensional environment, where all the objects exist on a flat plane. The camera is also set to capture only two dimensions, with no depth or perspective. In MIVis, 2D scenes are developed to build the graphical user interface (GUI) elements such as minimaps, text, and pop-up panels. These elements can be used to provide the player with additional information or to enhance the user interface.

A 3D scene in Unity is a three-dimensional environment in which objects have depth, height, and width. The camera in a 3D scene is typically set up to capture all three dimensions, with a perspective that mimics human vision. The terrains of Mitlenatch Island and its surrounding were built in the 3D scene and manipulated to create a realistic landscape. Viewing the scene from a first-person perspective gives users a sense of actually being in the environment.

In addition to creating 2D scenes and 3D scenes and environments, Unity 3D also provides tools for creating colliders. Colliders are essential for detecting and responding to collisions between objects in a scene. Unity offers several types of colliders, each with its own unique shape and behaviour. A few colliders that were used in MIVis:

- Object Collider: It defines the physical shape of a game object, allowing other colliders in the scene to interact with the object as if it were a solid object.

- Terrain Collider: It defines the physical shape of a terrain object, allowing other colliders in the scene to interact with the terrain as if it were a solid object.

- Trigger Collider: When another collider (i.e. the first-person character) enters or exits its boundary, but does not physically interact with them, a special event called OnTriggerEnter or OnTriggerExit is triggered in the script attached to the object with the trigger collider.

Lastly, in Unity, a skybox is a 6-sided cube that encompasses the virtual environment to create the illusion of a sky. It is a visual element that provides a sense of depth and realism to the environment.

Topography/terrain modelling

The first step was to prepare for the topography of the island. It was crucial to preserve the highest level of detail of the topography height in order to provide the user with an immersive experience as if they were actually 'on the ground' during the geovisualisation (Newell et al., 2017a). Using QGIS software, a Digital Elevation Model (DEM) was assessed for the quality of the raw data, including checking for errors, filling gaps, and removing redundancies. The DEM was then converted into a greyscale TIFF file, which was further processed using Photoshop to convert it into a greyscale RAW format for importing into Unity as a terrain heightmap. This process was based on the steps mentioned in Newell et al. (2017a) paper.

After the heighmap was created, it was translated to a 3D terrain GameObject in Unity 3D to create the landscape of the island. Unity 3D works in arbitrary units, and to import a RAW file into the program, it is necessary to specify the dimensions of the terrain. In this work, the model was developed by using a convention where one Unity unit is treated as one meter, and the terrain was accordingly scaled to the dimensions of 1,400 m in length, 1,400 m in width, and 54.5 m in height. Once the dimensions were defined, Unity used the grayscale values of the RAW file to extrude the terrain surface, with lighter shades being computed as higher elevations.

The terrain development process was repeated to create the viewshed around the island. Viewshed, which refers to the visible areas of terrain from specific locations (viewpoints), has become a commonly used technique in GIS and digital terrain modelling for interpreting, analysing, and visualising landscapes (Misthos et al., 2019). Incorporating viewshed elements into the model is crucial, as they significantly influence its representation of place (Newell et al., 2017a). A viewshed height map was incorporated into the model, representing the surrounding areas seen from Mitlenatch Island.

Terrain Texture

Once the terrain was created, a high-resolution orthophoto was overlaid on the island's terrain to add texture. This technique of applying surface textures plays a crucial role in capturing the true appearance of real-world objects in 3D geovisualisations (Dykes et al., 2005). However, this texture from the orthophoto was not perfect as it was a bird-eye view and very different from the view on the ground why (i.e., it also included vegetation canopy). Using Unity's 'paint texture' tool to add textures, such as grass, soil, and debris, to our terrain. Using this technique, the tree crowds replaced the tree crowns in the orthophoto with soil or grass textures, which more accurately reflect the ground cover in the area.

The next steps involved adding a sky and a water body around Mitlenatch Island. Adding a sky can give the environment a sense of space and atmosphere, while adding a water body can create

reflections and add realism to the scene. To add a sky in Unity, Skybox feature was used to render the

image via a Skybox Material which allowed used to choose from a range of sky textures and customise

the settings to achieve the desired look. Using the skybox feature has the advantage of eliminating the

need to create meshes or write any code (Ou et al., 2021). This enables the sky textures, colours, and

lighting to be easily adjusted in the Customisation panel, enabling seamless customisation of the skybox

to fit our specific environment. Once the sky was added, the next step was to add a waterbody. The

addition of a water body enhance the realism of the scene around the island. To create a more realistic

environment for the island, a water surface element was added to represent the surrounding water

body. Once the terrains, including the viewshed terrain, were created, the texture was painted, the

water elements, and the skybox was added, and the geovisualisation took on the appearance shown in

Figure 7.
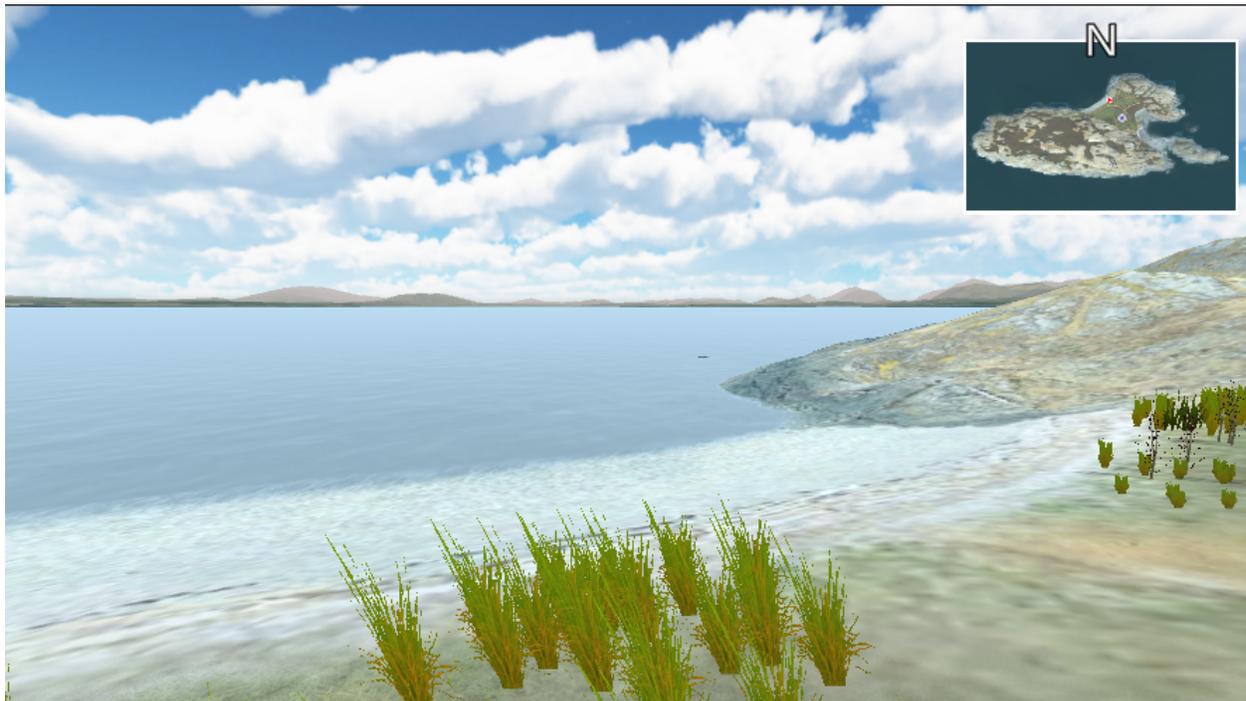
Figure 3: User's view after including the skybox and viewshed.

Objects and vegetation

Object elements and vegetation were incorporated into the geovisualisation, as shown in Figure 8. Object elements refer to objects/items that are positioned within the virtual environment where users can navigate. Most of the objects were non-intractable, meaning users cannot manipulate them. These types of objects are mostly static (with the exception of small animations, like vegetation swaying in the wind) and exist for the purpose of enhancing realism and mimicking the real world.

Bushes, grasses, and other small plants were built as "terrain detail" items to add visual complexity and realism to a terrain surface without having to create and manage a large number of individual GameObjects. This improved performance by reducing the number of individual objects that need to be rendered, and by allowing for the use of lower-poly models and textures for objects such as grass and vegetation (Newell et al., 2017a). Object colliders were applied to certain object elements to prevent users from walking through them. For instance, a tree with a collider cannot be passed through by the user. Such objects include a volunteer cabin (Figure 8C), trees, rocks, and logs around the seaside areas.
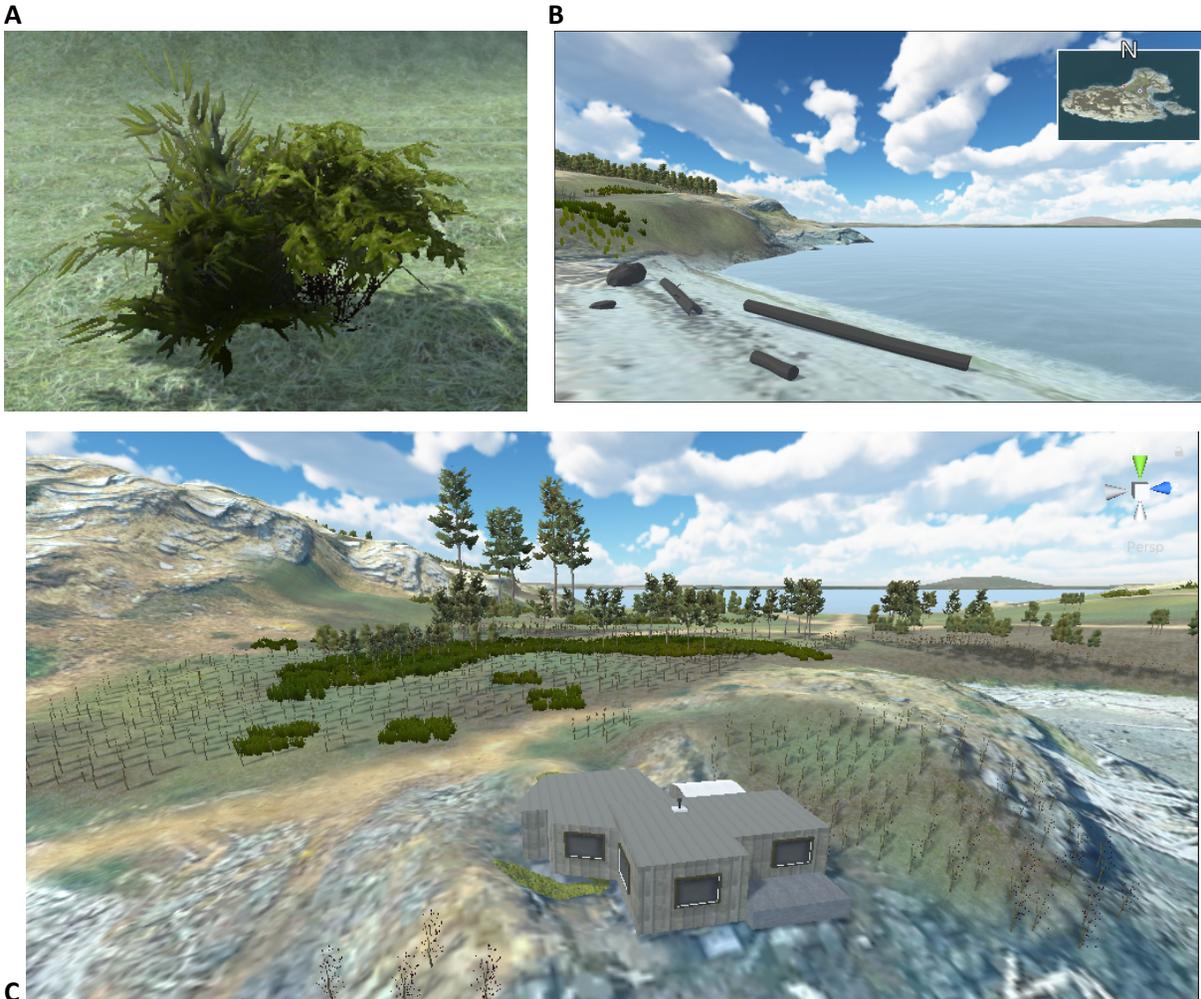
Figure 4: 3D Objects in MIVis.
Himalayan blackberry model (A); Rocks and logs found around the seaside (B); Volunteer Cabin on Mitlenatch Island (C).

Himalayan blackberry plots

A 'reference map' was created using the map of Himalayan blackberry locations shared by BC Parks (Figure 9), which was fitted onto the terrain assets and used as a reference for positioning Himalayan blackberry plots. This reference map was used as a reference to map the Himalayan Blackberry bushes on the 3D terrain. The Himalayan blackberry map was imported into GIMP and adjusted to fit the terrain assets in Unity, considering their orientation and extent. Subsequently, the reference map applied to the terrain surfaces in Unity while temporarily disabling the original texture

maps. This enabled the reference map to be visible and serve as a guide for the positioning of the

Himalayan blackberry plots.

Figure 5: Himalayan blackberry plots on Mitlenatch Island (Maslovat et al., 2019).

The Vegetation Spawner (Figure 10) was used to model the densities of Himalayan blackberries

inside the pots, which is a procedural modelling tool for populating terrain with vegetation in a rapid

and efficient manner. The tool was used to control the density of Himalayan blackberry, which proved to

be helpful when visualising the difference between the pre- and post-treatment stages. It was equipped

with a "Layer mask" to specify where to place vegetation. Specifically, the vegetation changes were

restricted to the Himalayan plots.
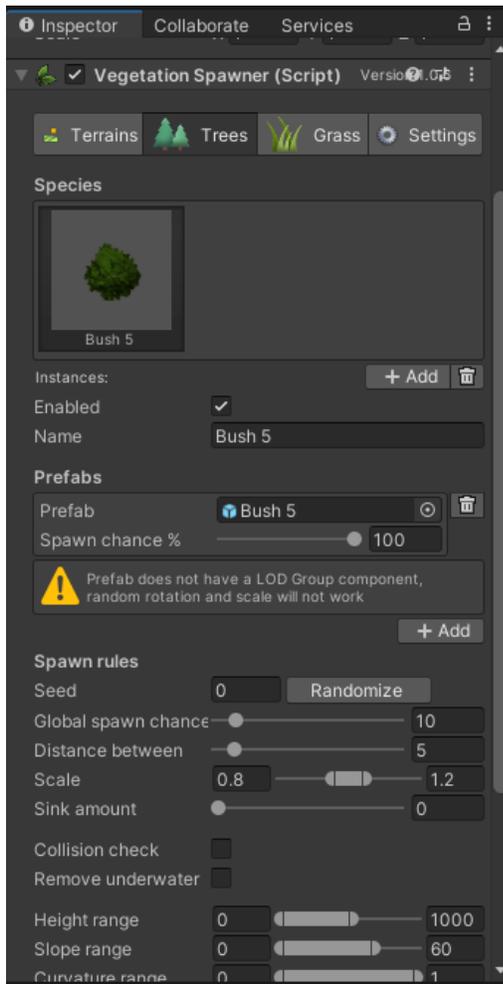
Figure 6: Vegetation Spawner configuration on Unity 3D.

Himalayan blackberry trigger

A trigger collider was set up around the Himalayan blackberry plots, which activate a text pop-

up (Figure 11) whenever a user enters it. The pop-up provides information that informs users that they

are near and/or viewing the Himalayan blackberry plots and how to active the scenario exploration

feature. Once users moved away from the Himalayan blackberry plots and leaves the trigger collider, the text pop-up is no longer accessible.

Figure 7: A text pop-up would appear when User entered the "trigger collider."

Scenario Exploration

When accessing the scenario explorer feature in MIVis, the mouse cursor becomes enabled, allowing users to toggle and navigate through the scenarios via buttons. The buttons are clicked to select different scenarios and perform actions such as restarting, minimising, or closing the pop-up panel for the Himalayan blackberry (Figure 12). Different scenarios were created as separate GameObjects, each with its own visual representation and user interface. To switch between scenarios, users can click on buttons that load the respective scenario and stage.

The Himalayan blackberry pop-up panel was constructed using UI components, including the buttons in the 2D Scene view. These buttons were decorated with icon images, downloaded from Icon8 (https://icons8.com/). After selecting the appropriate images for the buttons, an 'on-click' C# script was created to trigger when the button was clicked (Figure 13).

As an example, these were the steps taken to create the 'close' button. First, an image was added that resembled a cross to the 2D Scene view and positioned it correctly within the scene. Next, the Button component was assigned to the image and the button's appearance was customised by changing its colour to red when hovered over to indicate its clickability (which follows commonly used conventions in Windows and MacOS). The OnClick() command in the C# script was utilised to define the button's action and specify what should happen when the button was clicked. In this case, the action that was defined was to close the scenario pop-up panel.
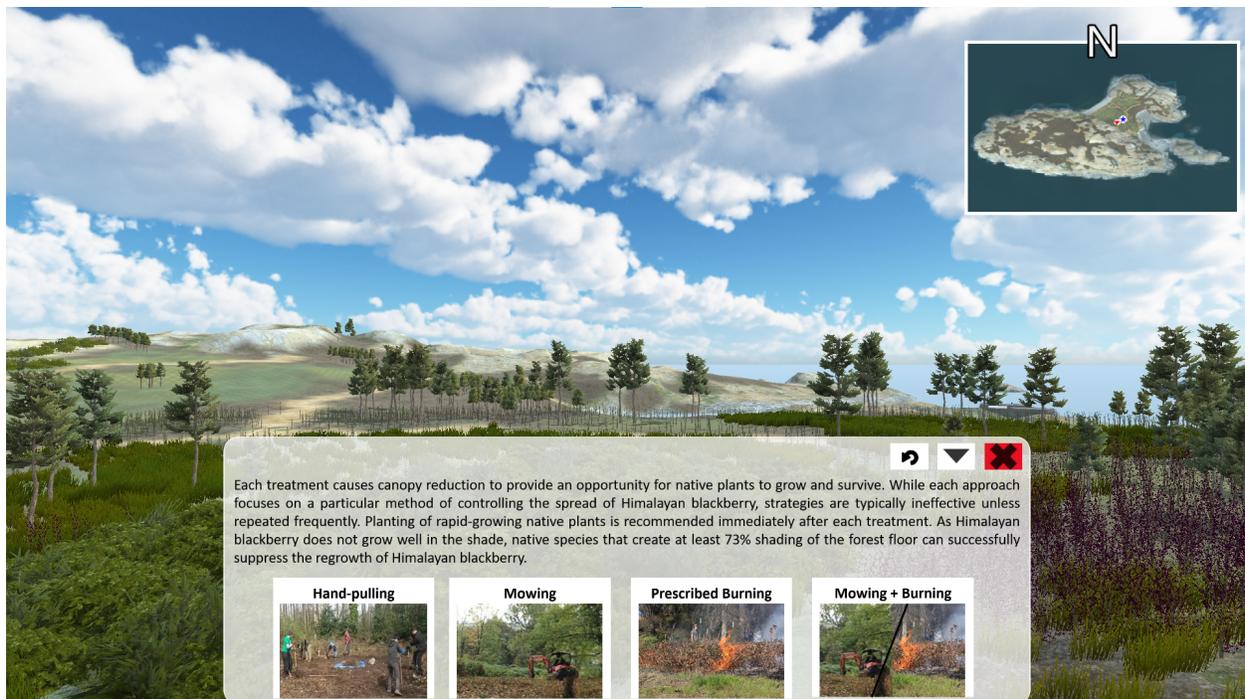
Figure 8: Pop-up panel 'Close' button will change colour to red when hovering over.
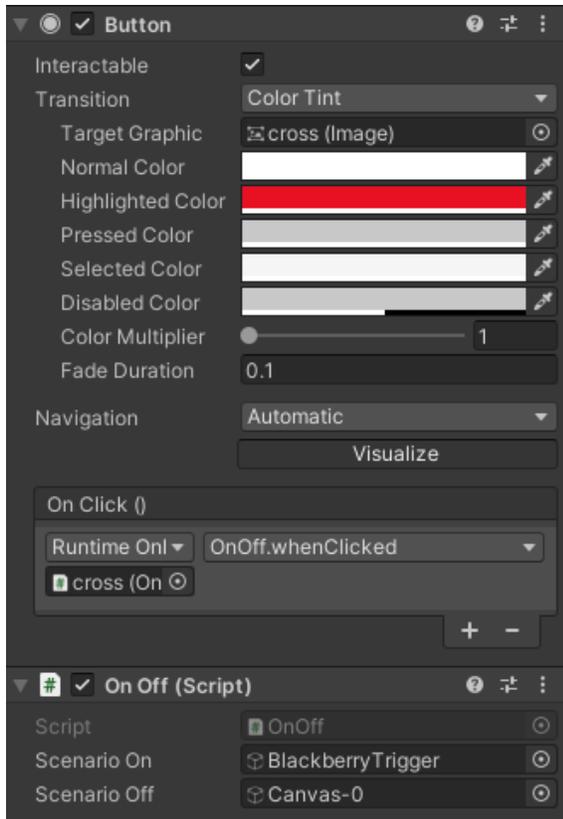
Figure 9: Button configuration in Unity 3D.

User Character

The geovisualisation was experienced from the first-person perspective, and the camera was vertically set to emulate a visitor of a height of approximately 170 cm. The first-person perspective was made invisible, also known as "ghost mode" in video games. In this mode, the users can observe the game world from the perspective of their character, but the character itself is not visible to other players or in-game entities. The virtual camera moves at a pace of 6 km per hour while navigating the virtual environment, which is comparable to the average walking speed in the real world. However, choosing a faster walking speed was necessary to enable users to navigate the virtual environment at a reasonable pace (Newell et al., 2017b). Research conducted by Bishop and Rohrmann (2003) indicates that

individuals perceive their movements in virtual environments as slower than the actual speed of the camera.

Users control their characters using and interact in MIVis using their keyboards and mice to move around the virtual island and perform actions. Visualisation interfaces that use keyboards and mice demand user attention, which can distract them from thinking about and discussing a problem (MacEachren et al., 2004). The choice to use mice and keyboards was driven by their widespread availability, accessibility, and ease of use. These input devices have become ubiquitous in modern computing due to their familiarity as most of us interact with our computers/laptops using mice and keyboard.

Minimap

A minimap was included in the geovisualisation, located in the top right-hand corner of the screen. It is a simplified and compact 2D/bird-eye overview of the game world, allowing users to orient themselves quickly and see where they are in relation to the rest of the island. The main purpose of the minimap is to help users navigate through the island, making it easier for them to find their way around.

To create the minimap in the geovisualisation, a separate camera was created to capture a top-down view of the island. This camera was positioned above the island and set to capture a rendering of the entire island from a bird-eye perspective, and this camera view was projected onto a rectangular UI element located in the top right-hand corner of the screen. To assist users in orienting themselves, a north arrow icon was included. Additionally, a red arrow was added to highlight the first-person character's position, as the character is in 'ghost mode' and not visible on the minimap.

Soundscape

To enhance users' experience with the geovisualisation tool, a soundscape was integrated into MIVis. This acoustic environment provides a sense of immersion and helps to create a more realistic and natural ambiance (Newell et al., 2017a). Sounds such as wave crashing and wind blowing were included, with ocean sounds downloaded from Sound Bible (https://soundbible.com/). The audio source settings, such as volume and play on loop, were adjusted and the timing of the sounds was specified for when users are in first-person perspective mode.

Users' experience/Gameplay

This section discusses how MIVis tool functions from the users' perspective, including details on the tool's interface, its capabilities, and how users can interact with it. When users first launch MIVis, they are presented with an introduction page that familiarises them with the project (Figure 14A). The 'Next' button, which is highlighted by a change in colour to blue when hovered over with a mouse, indicates that it is ready to be clicked. After clicking 'Next', users are then directed to the next page, where they are presented with the project's objective, along with a set of instructions on how to use the application. Once users have read and understood the instructions, they can then initiate the first-person perspective experience by clicking the 'Start' button (Figure 14B). The application was designed in this manner to ensure that users are informed on how to use it and get the most out of the experience.
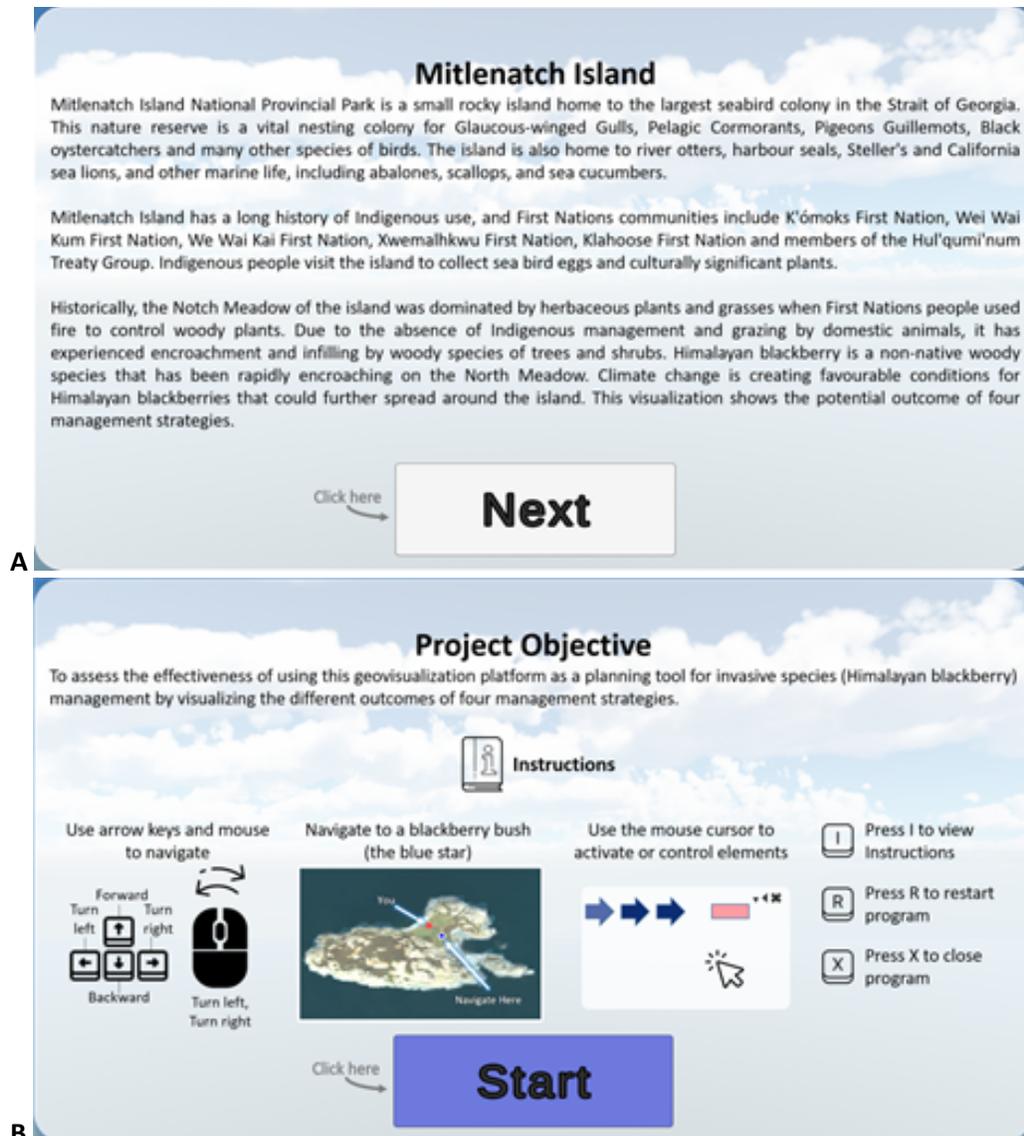
Figure 10: Introduction page of MIVis.
Introduction page of MIVis (A); Subsequent page displaying the objective and a set of instructions on how to use the geovisualisation (B).

A first-person character mode is activated for users, allowing the geovisualisation to be viewed and navigated from a first-person perspective (Figure 15). Users are free to explore the island as they see fit. Users can use the arrow keys or the WASD keys to move their character around the island. The up arrow or W key typically moves the character forward, while the down arrow or 'S' key moves the character backward. The left and right arrows or 'A' and 'D' keys rotate the character left and right,

respectively. In addition to using a keyboard, the user can move the camera viewing by moving their mouse left, right, up, or down.

To help users navigate through the island, a minimap was added to the top right-hand corner of the screen, which shows the users' location and surrounding area. As users explore the island, they will encounter various sensory features, such as the sound of rustling leaves and the wind blowing through the trees. Features and dynamics in the virtual environment, such as the sun and shadow effect and the ocean waves lapping against the shore, are included to enhance the sense of realism in the geovisualisation experience. The minimap helps players keep track of their location and where they need to go, while the sensory features create a dynamic and engaging environment that draws players into the game's world.
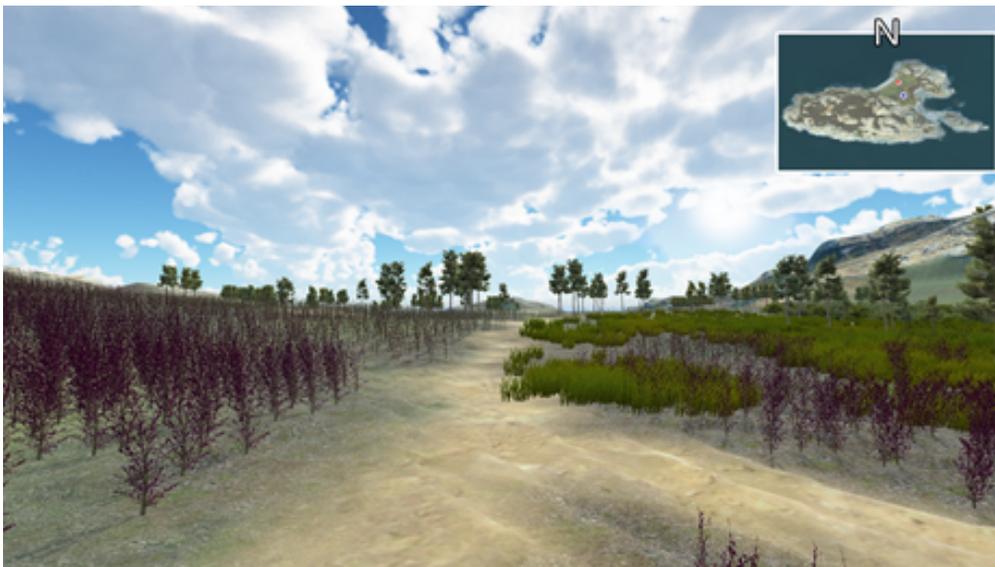
Figure 11: First-person perspective.

When users approach the Himalayan blackberry plot, a pop-up prompt will appear on the screen to inform them of its presence (Figure 16). This small text box overlaid on top of the screen prompts the player to press the 'B' key to view more information about Himalayan blackberry. The purpose of the

pop-up is to provide clear guidance to the users and make it easy for them to interact with Himalayan blackberry. This pop-up prompt disappears when the users move away from the plot.

Figure 12: A pop-up prompt activated near a Himalayan blackberry plot.

By pressing the 'B' key, users will be able to see a pop-up panel that provides relevant details about Himalayan blackberry (Figure 17). This feature is designed to improve the overall experience and help users navigate the geovisualisation more efficiently. Additionally, by clicking on the 'Future unmanaged scenario' button, users can visualise how the environment might look like in the future if they choose to leave it unmanaged (Figure 17B). These features are intended to create an engaging and informative experience for users.
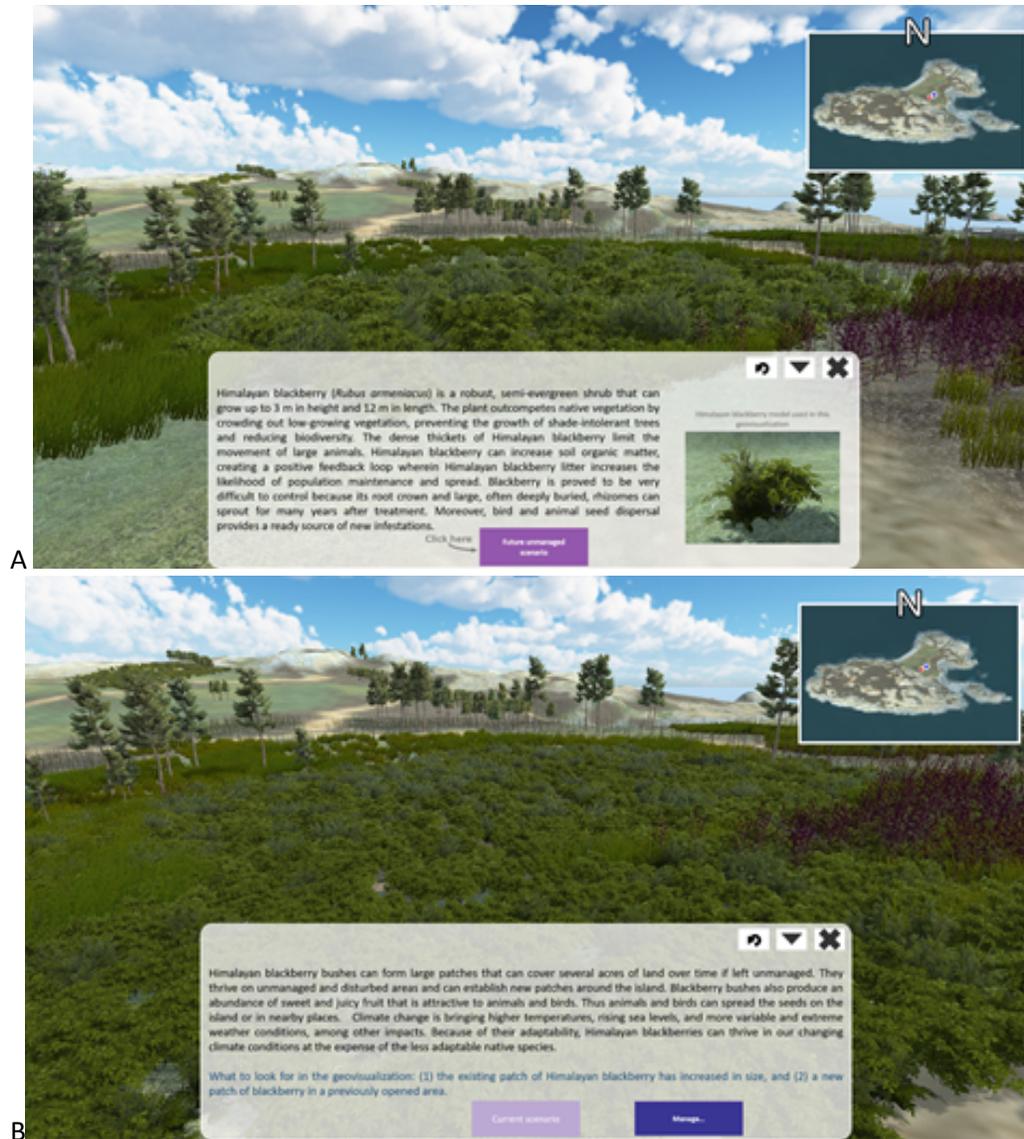
Figure 13: Himalayan blackberry pop-up panel (A); Scenario of future unmanaged scenario (B).

Clicking on the 'Manage' button provides the user with a range of management strategies to choose from. To select a strategy, the user needs to click on the corresponding image of the strategy that they want to implement (Figure 18A). As an example, if users want to view the hand-pulling management strategy. When users click on the hand-pulling image, detailed information about the strategy will be displayed, including an image that provides a visual representation of how the management strategy would look like (Figure 18B). At this stage, users also have an option to view the

expected outcomes after the treatment and after one growing season by clicking on the relevant

buttons. When users select the option to view the post-treatment outcome, they can do so by clicking

on the 'After Treatment' button. Upon doing so, they will be presented with a visual representation of

the scenario along with accompanying text to explain the scenario in detail (Figure 18C). When users

click on the 'After one growing season' button, they will be presented with a visual representation of the

corresponding stages and accompanying text that provides an explanation (Figure 18D).
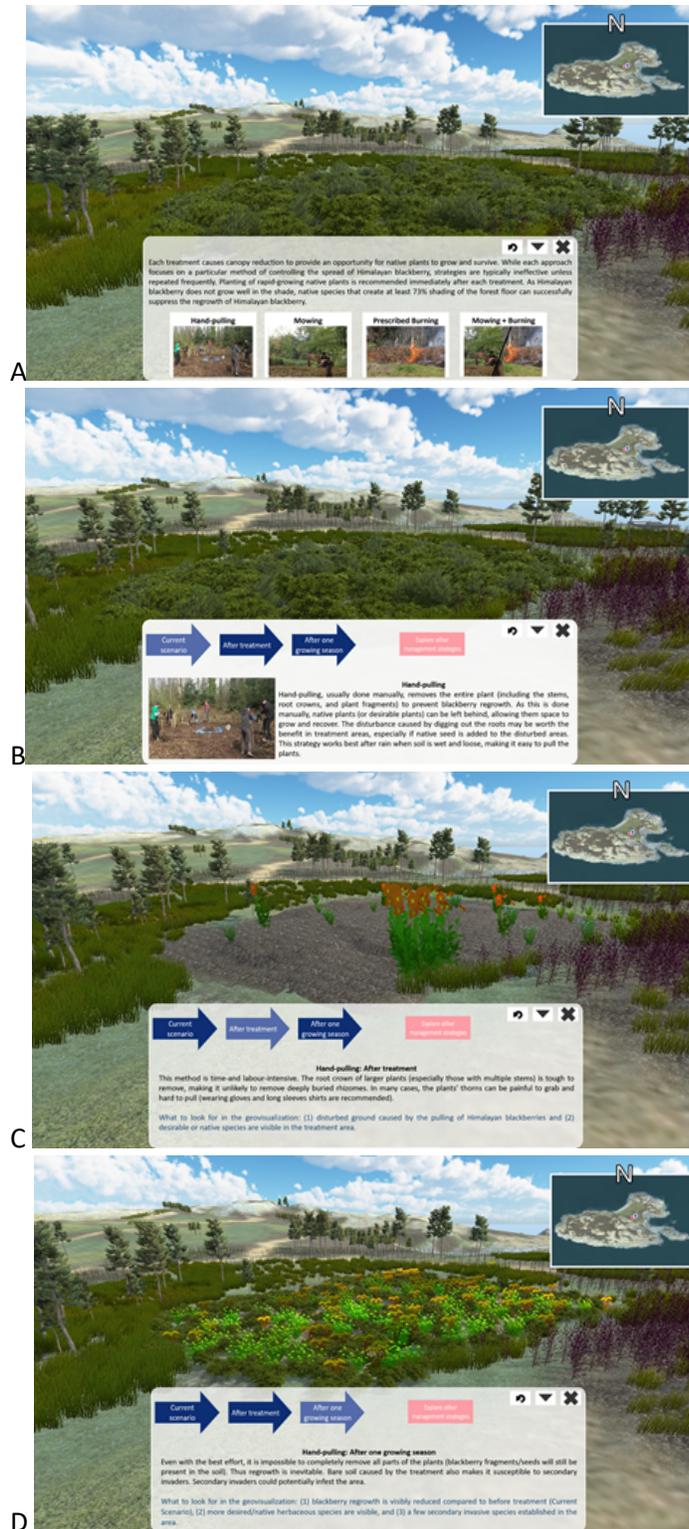
Figure 14: View of Himalayan blackberry management stages. Options to view the four management strategies (A). Hand-pulling strategy; (B); 'After treatment' stage (C); 'Scenario after one growing' stage (D).

At any moment when users are accessing the pop-up panel, they have an option to switch to a different management scenario by clicking on 'Explore other management strategies' button, refresh the pop-up to return to its first page ('Refresh' button), minimise the panel ('Minimise' button), or close it altogether ('Close' button). When the pop-up panel is minimised, the user has the option to maximise it and return to the previously viewed page (Figure 19).

Figure 15: Geovisualisation when Himalayan blackberry pop-up panel is minimised.

Reflection

Building the geovisualisation presented several choices and trade-offs that had to be carefully considered. One of the main challenges was the availability of data to represent Mitlenatch Island. Since there were limited data about Himalayan blackberry with respect to the appearance of different management treatments, the use of photos from the internet became the primary source for visual presentation of the scenarios during the development process. While this allowed for a visual representation, it also posed limitations in terms of accuracy and authenticity.

Practical considerations, such as time and funding limitations, played a significant role in shaping the choices made during the development of the geovisualisation. Limited resources meant that extensive data collection or additional field trips were not feasible within the given constraints. However, it is important to acknowledge that engaging experienced users in the development process could have provided valuable insights and enhanced the authenticity of the visualisation. A more inclusive and collaborative approach could be adopted to compensate the lack of available data. By including experienced users and working in iterations during the development process, the geovisualisation could became more representative of the island.

Moving forward, it is recommended to prioritize data collection efforts and involve experienced users throughout the planning and development stages. This collaborative approach can help ensure that the geovisualisation reflects the needs and perspectives of the intended audience, increasing its relevance and potential impact. Additionally, seeking opportunities to gather more specific and accurate data, whether through focused field trips or collaboration with relevant experts, would contribute to the overall quality and credibility of the tool.

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