Interactive 3D visualizations of environmental data using the terrainr R package

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Abstract

Assessing visual resources to inform environmental decision-making typically requires developing 3D renderings of the landscape, allowing stakeholders to contextualize the impacts of a decision on the surrounding area. In particular, visualizations can be particularly valuable for improving public participation in decision-making activities, serving as a “common language” or “translation layer” for communication between expert and generalist audiences. These visualizations are more effective when they are higher resolution, with increased realism and visual fidelity; however, producing these sorts of highly-effective visualizations has historically required designers to have access to larger amounts of computational power and technical knowledge than more traditional forms of scientific visualization.

This paper introduces a new method for developing these interactive visualizations, leveraging the Unity 3D rendering engine and the R programming language to programmatically produce high-resolution 3D landscape simulations. By walking through how this process might be applied to a standard viewshed analysis, we demonstrate the advantages of this interactive format in allowing the user to more easily investigate presented data and modeled outcomes. Through manual adjustment to further improve realism and simulate management outcomes, this technique has the potential to be useful in a wide array of visual resources applications.

# 1 Introduction

Environmental decision making is a complex process, requiring stakeholders of varying educational and professional backgrounds to communicate and negotiate about differing environmental value systems to determine a mutually-agreeable course of action (Metze 2020). One of the key challenges in this process is the translation of background knowledge and expertise between stakeholders, particularly as members of the public become increasingly involved in making decisions about landscape management. For this reason, visualizations have often been described as a “common language” which may help stakeholders understand one another more effectively, allowing stakeholder values, background knowledge, and statistical information to be communicated in a more intuitively understandable format (Nicholson-Cole 2005). In particular, interactive visualizations may allow stakeholders with less formal training more agency to explore data and modeled outcomes on their own, potentially identifying preferred alternatives or problematic assumptions baked into the presented analysis. To this end, interactive simulations have been used for engaging the public to great effect in domains such as transportation policy (Lovelace, Parkin, and Cohen 2020) and urban planning (Pettit et al. 2015).

However, many environmental problems don’t lend themselves to the types of interactive graphics that have flourished elsewhere While some metrics may be easily plotted, others (such as visual impact, ecological integrity, or land management histories) require more context than can be communicated through standard visualizations. While interactive 2D maps are able to provide some spatial context to data, they often still require users to think about a landscape in a highly abstract way, attempting to match colors on a map to regions of a color key located elsewhere, match symbols to values in a legend (or to values implicitly assumed to be understood), and to convert pixel distances and areas into their real world equivalents. This level of abstraction can make maps rather difficult to understand, limiting their value as a translational tool (Ottosson 1988).

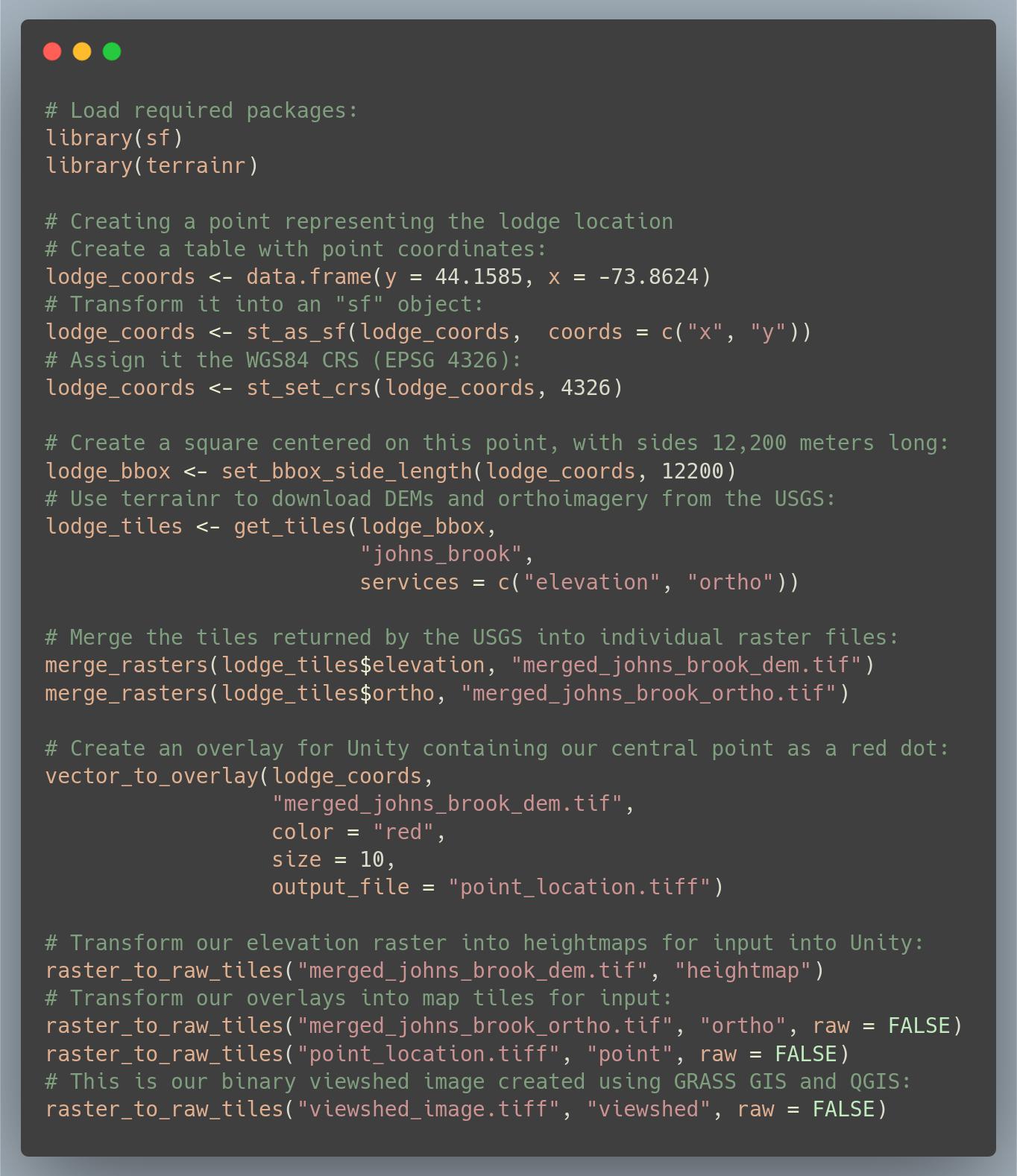
This limitation may be overcome by creating more true-to-life renderings of an area of interest, visualizing landscapes more similarly to how they might appear in the real world. This practice is already prevalent in visual resources management, with realistic renderings of proposed management activity a common stage in many decision making processes (Molina-Ruiz et al. 2011; Szumilas-Kowalczyk and Pevzner 2019). These visualizations are more effective when produced at higher resolutions, with increased realism and visual fidelity (Appleton and Lovett 2003); however, producing these highly realistic renderings typically requires more computational power and technical knowledge than more abstract 2D maps (Paar 2006).

Game engines have been proposed as a potential solution for the demanding requirements of producing these renderings (Herwig and Paar 2002). These programs, specifically tuned to render terrain at high resolutions quickly enough so that players in a video game won’t notice any computation lag, can simulate large-scale landscapes using mass market computer equipment. The most popular of these engines, the Unity real-time development platform (Unity Technologies 2020), has been used to produce 3D landscape visualizations since at least 2010 (Wang et al. 2010). However, while Unity solves many of the computational obstacles to the use of large-scale 3D renderings, it still demands a high level of skill and familiarity for users to produce landscape visualizations. Perhaps for this reason, Unity is still under-utilized as a tool for 3D landscape visualization.

This paper describes the terrainr package (Mahoney 2021), an extension for the open source R programming language (R Core Team 2020) which assists users in retrieving, manipulating, and transforming spatial data for importing to Unity, and illustrates how this package may be used as part of a workflow for visualizing visual impacts and viewsheds. By depicting landscapes in a more concrete form than typical 2D maps, this workflow produces renderings that may be more intuitively understandable for a generalist audience, serving as an effective tool for translating between stakeholders in an environmental decision making process.

# 2 Viewshed Analyses with terrainr

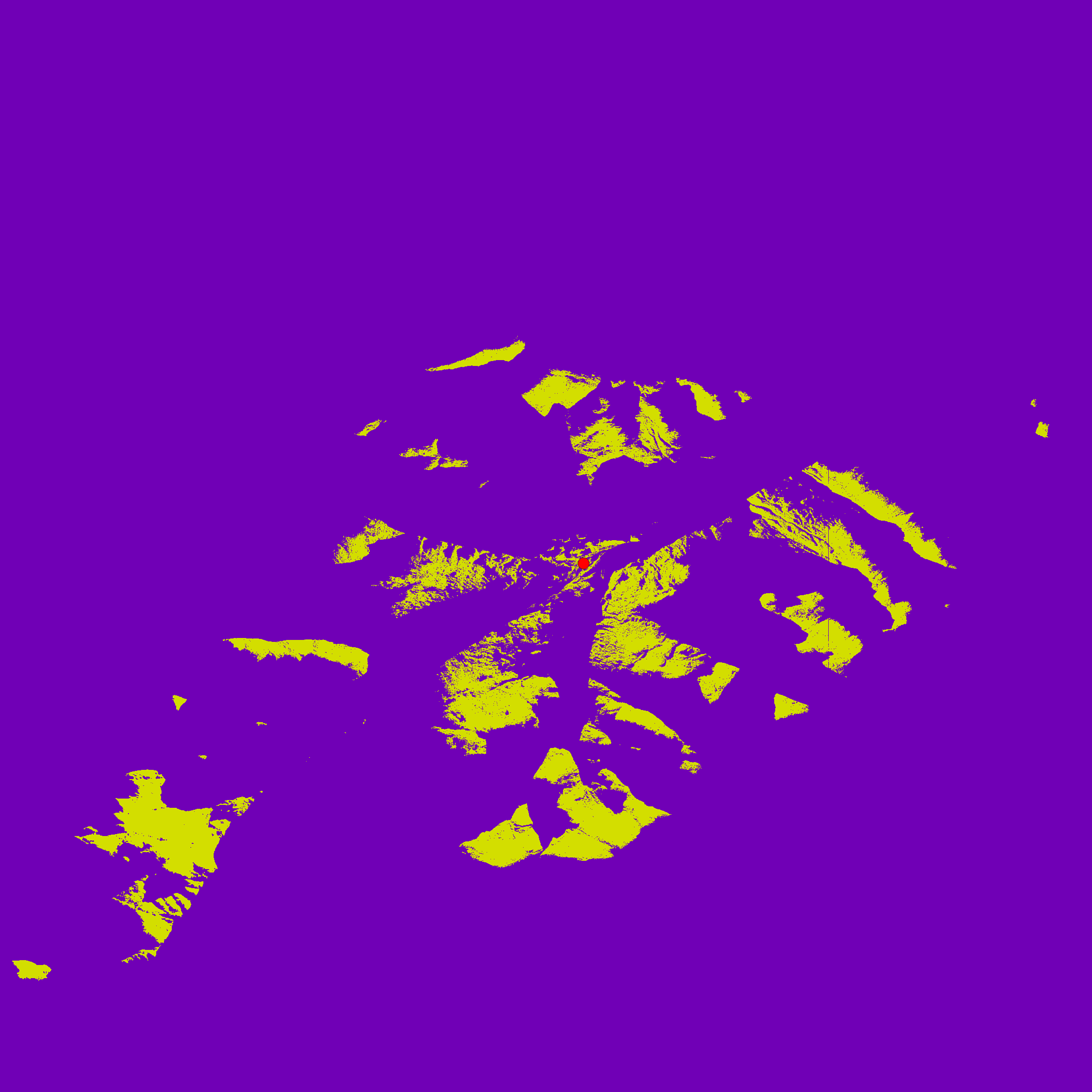
To illustrate the potential of high-resolution 3D simulations for visual resources management, we will walk through an example viewshed analysis using both traditional 2D mapping and Unity. As an example, we will examine the viewshed impacted by the Johns Brook Lodge building, a privately operated resort located within the Eastern High Peaks wilderness area of the Adirondack State Park. All code required to reproduce this section is included as Figure 1; we will not focus on defining functions and parameters here but rather defer to the documentation provided with the sf and terrainr packages (Pebesma 2018; Mahoney 2021).



(#fig:code\_required)All the R code required for the visualizations incorporated in this paper. In addition, viewshed calculation was done using GRASS GIS version 7.8, with the outputs saved as an image using QGIS. Descriptions of functions and their arguments is available online at <https://docs.ropensci.org/terrainr/>

The initial step in this process is to define our area of interest. We first define a point located at Johns Brook Lodge (44.1585 N, 73.8624 W), then convert it into a “simple features” object using the WGS 1984 coordinate reference system (EPSG code 4326) using functions provided by the sf package (Pebesma 2018). Next, we use functions from terrainr to define a bounding box centered on the lodge, with side lengths of 12,200 meters. We then are able to use this bounding box to download a bare earth digital elevation model (DEM) and orthoimagery from the USGS National Map (U.S. Geological Survey National Geospatial Program 2020). As the USGS National Map is not able to return rasters representing our full bounding box in a single query, the get\_tiles function returns our data as a set of multiple map tiles, which we are then able to merge into cohesive individual rasters using the merge\_rasters function. With approximately ten lines of code, we are able to define our area of interest, retrieve public domain data for this area, and process the downloaded data into singular files which are easier to work with than separate tiles.

Unfortunately, identifying viewsheds cannot be implemented so easily. For this process, we instead turn to the GRASS GIS function r.viewshed, run interactively through the QGIS interface [GRASS Development Team (2020); QGIS\_software]. By instructing the program to produce a boolean raster, indicating only whether a given pixel is or is not able to see the lodge, we produce the viewshed map presented as Figure 2. By changing the default symbology of the map such that the viewsheds are entirely transparent, and the other areas a slightly transparent black, we can overlay this raster upon orthoimagery to produce a more contextualized map; this is presented as Figure 3.



(#fig:boolean\_viewshed)A map showing the visibility of the Johns Brook Lodge (red dot), produced in QGIS. Yellow polygons are able to see the lodge, while purple regions cannot.



(#fig:ortho\_viewshed)A map showing the visibility of the Johns Brook Lodge (red dot), produced in QGIS. Brighter regions are able to see the lodge, while shaded areas cannot.

At this point, we save our re-symbolized raster as an image and return to R to produce our 3D visualization. In our final lines of code, we produce an additional raster image containing a red dot at our lodge, and then produce map tiles which may be imported into Unity through repeated use of the raster\_to\_raw\_tiles function. By importing these tiles into Unity, a process documented by the “Importing terrainr tiles into Unity” vignette included with the package, we are able to quickly produce a 3D replica of this visualization inside the game engine. When viewed isometrically from above (Figure 4), this rendering is incredibly similar to Figure 3; the only obvious evidence this is a different image is the smaller marker indicating the lodge.

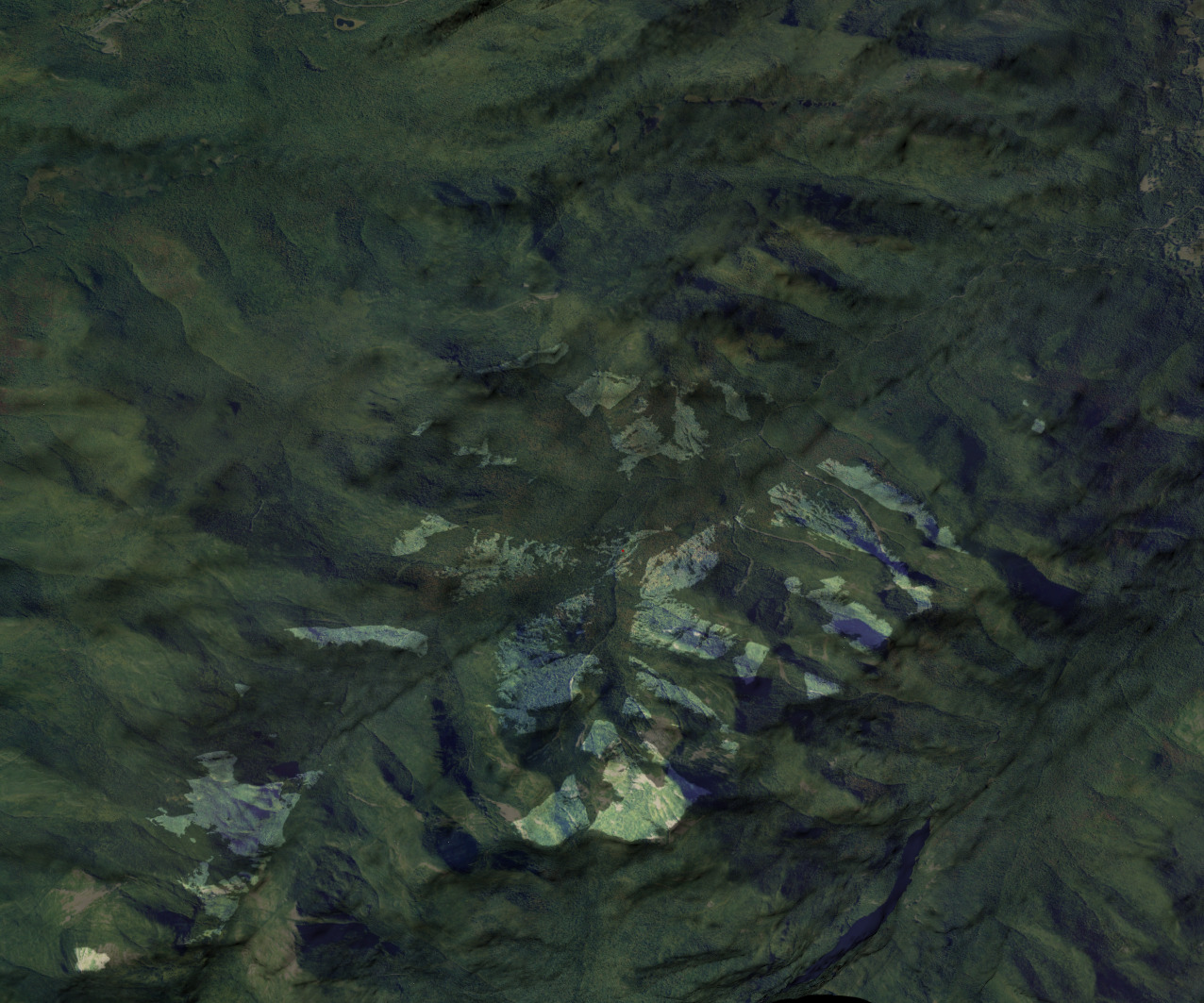


Figure 2.1: A map showing the visibility of the Johns Brook Lodge (red dot), produced using the Unity rendering engine. Brighter regions are able to see the lodge, while shaded areas cannot.

Of course, users are not restricted to viewing their landscape as a flat surface from above. By moving the camera throughout the scene, users are able to investigate how viewsheds interact with terrain and features in orthoimagery (Figure 5; Figure 6). This control allows for a new depth of interactivity with the visualization of model outputs; for instance, a user might validate the results of the viewshed operation by placing themselves at the feature of interest and searching for shaded regions (Figure 7). In total, this interactive 3D model allows users a greater degree of autonomy when exploring model results and provides additional context not present in the 2D map incorporating the same data.

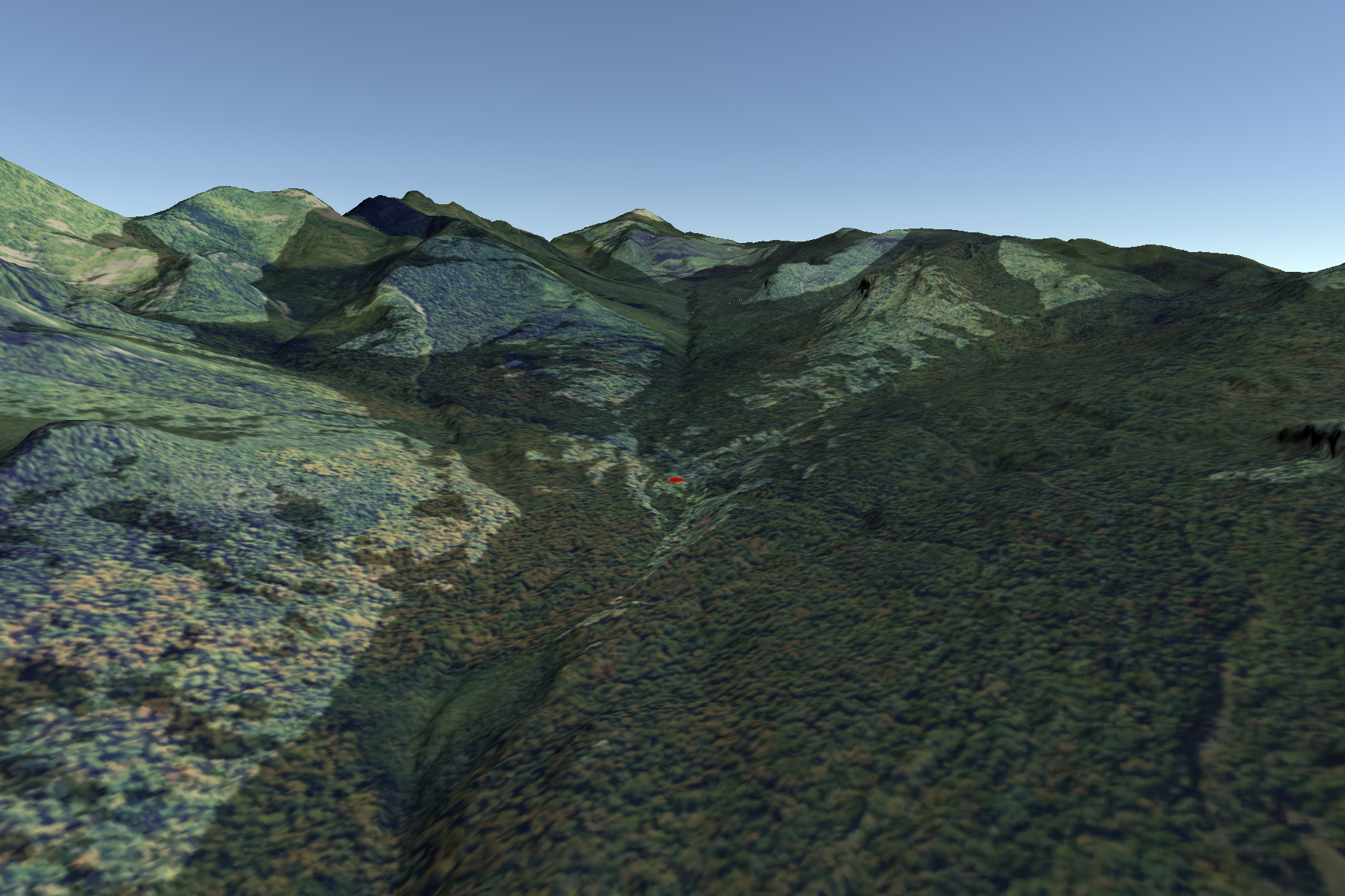


Figure 2.2: A map showing the visibility of the Johns Brook Lodge (red dot), produced using the Unity rendering engine. Brighter regions are able to see the lodge, while shaded areas cannot. This image is taken facing towards the southwest, so that Mt. Marcy is approximately centered in the horizon. Users are able to manipulate the camera to reposition themselves throughout this scene and investigate model outputs in various regions.

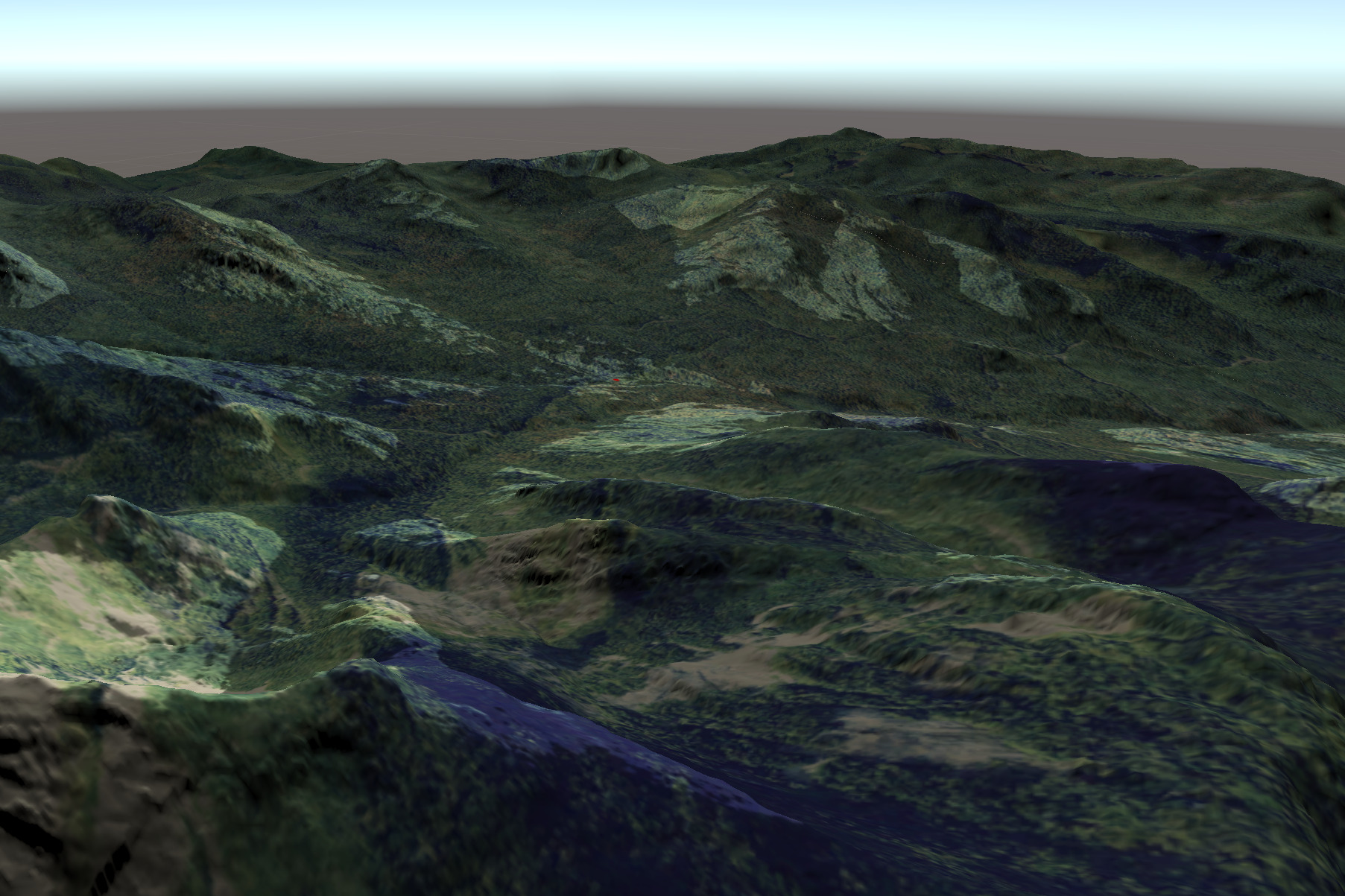


Figure 2.3: A map showing the visibility of the Johns Brook Lodge (red dot), produced using the Unity rendering engine. Brighter regions are able to see the lodge, while shaded areas cannot. This image is taken from Algonquin Peak facing east towards Giant Mountain. Users are able to manipulate the camera to reposition themselves throughout this scene and investigate model outputs in various regions.

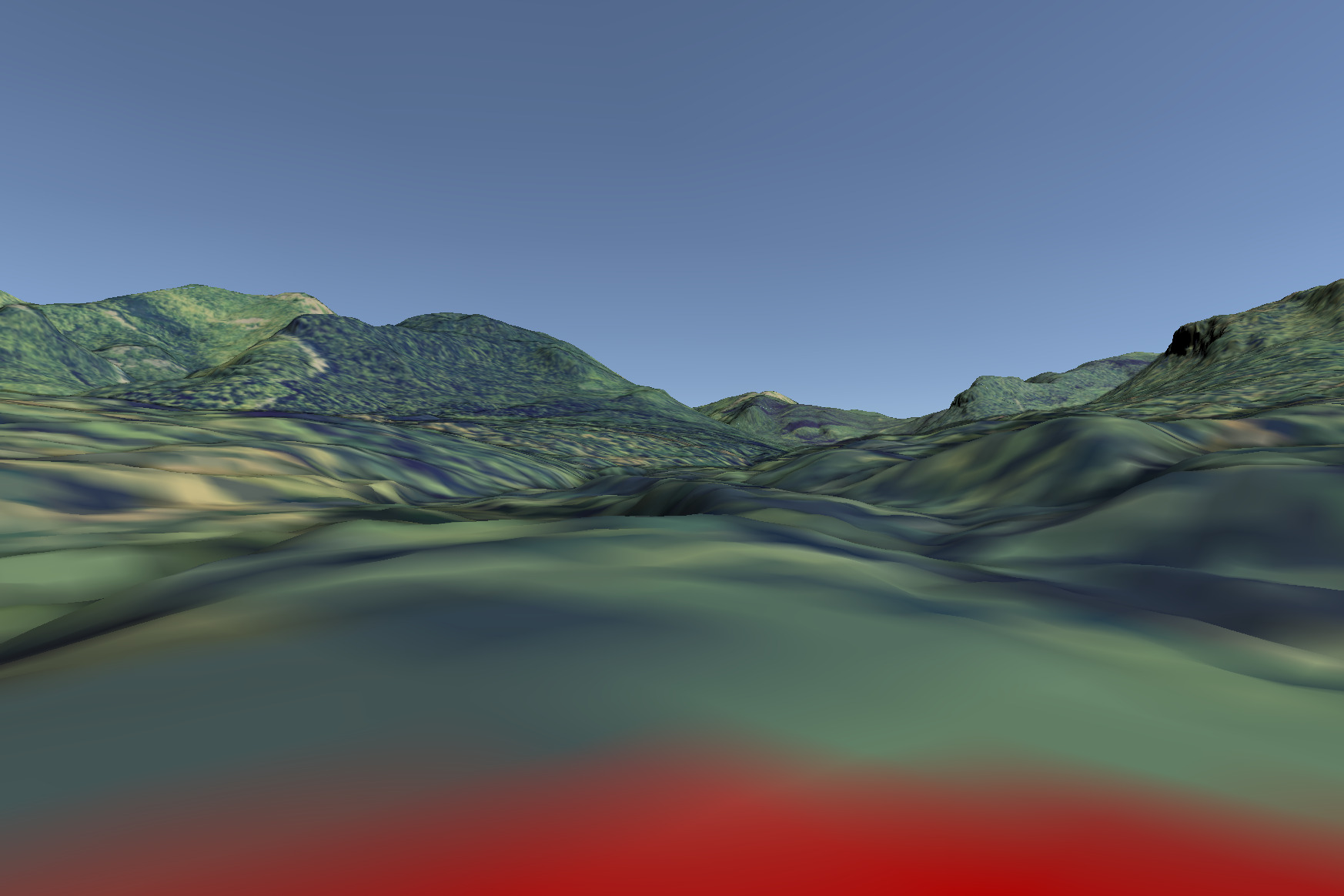


Figure 2.4: A map showing the visibility of the Johns Brook Lodge (red dot), produced using the Unity rendering engine. This image, taken from the location of the lodge itself, is entirely highlighted, allowing users to verify that the viewshed algorithm has correctly identified areas which may be seen from the lodge.

# 3 Discussion

Interactive visualizations present an exciting opportunity for engaging stakeholders in environmental decision making processes, helping nonspecialist participants investigate data and models through friendlier interfaces than those used by the professional analyst or researcher. In particular, high-resolution landscape visualizations are particularly well suited for communicating many classes of environmental data, given the importance of spatial context to the interpretation of data and results. By making it easier to produce these visualizations, the terrainr package aims to make this tool more viable for land managers and environmental practitioners to incorporate into their decision making and outreach processes.

These 3D simulations are capable of effectively reproducing the outputs from traditional GIS-based analyses (Figure 3, Figure 4), but then allow users the freedom to explore the presented results in order to develop questions and draw their own conclusions about the performed analysis. This freedom may be useful when seeking to engage external stakeholders in a decision making process, as the interactivity allows users to surface and focus upon oddities and assumptions in the presented results which may have been masked in static visuals. By the same token, however, these visualizations are inherently less directed than static graphics or pre-developed video renditions, which may make it harder to present arguments and persuade an audience through this medium. Whether this is a benefit or a limitation of the approach is inherently dependent upon the goals of any particular visualization project, as well as one’s beliefs about the roles of researchers and other stakeholders in interpreting results and coming to decisions.

The visualizations presented in this paper have purposefully been restricted to those which may be programmatically generated using only terrainr and other publicly available open-source software products, without requiring a large degree of manual design or manipulation to produce. However, the Unity engine is capable of displaying hundreds or thousands of objects on top of these terrain layers for more realistic simulations. This allows users to place, for example, purchased models of trees at strategic points throughout the landscape to present the look and feel of a setting more realistically, or to place models of wind turbines to demonstrate the expected impact of a development project. There does not exist at this time a way to programmatically develop objects for these renderings in the way terrainr aids in the development of terrain tiles; this gap presents a clear direction for future work in this arena.

# 4 Conclusion

Effective visualizations can serve as a critical “translation layer” for environmental decision making, aiding in the communication of information and value systems between stakeholders of different educational and professional backgrounds. The increasing importance of public involvement in decision making processes has driven an increase in interactive visualizations, which may allow nonspecialists greater agency in investigating data and models and identifying alternative solutions. To this end, this paper has presented a new method for producing interactive 3D landscape visualizations, including a demonstration of how the method might be applied to viewshed analyses. This method allows users to explore and validate presented results, and provides these results with more spatial context than most traditional 2D mapping approaches. If combined with manual placement of objects such as trees, buildings, or wind turbines, this class of visualization presents an exciting opportunity for many aspects of visual resources management.

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