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ANALYSIS AND GEOVISUALISATION OF BIODIVERSITY MONITORING DATA

Diploma thesis

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ANOTATION

The main aim of this diploma thesis is to analyse openly available biodiversity data and use geovisualization techniques to create a series of educational resources on local biodiversity and selected geo-aspects. National Parks are a stronghold for preserving natural habitats and the wildlife that reside in them. Environmental education is key in communicating the importance of conservation and raising awareness of local biodiversity and the threats they face. Biodiversity data can be highly complex and copious in quantity. Therefore, simplifying and appealingly condensing this data is essential to educating the general public on the importance of their local wildlife and landscapes. This thesis utilised geovisualization methods to provide an interactive educational web platform using Glenveagh National Park, Ireland, as a case study. The goal was to educate potential park visitors, with particular focus on school-aged children about local ecosystems and biodiversity using selected geo-aspects. A brief analysis of local species and the surrounding landscape was conducted to create an educational website using geovisualization techniques to create a series of interactive maps and learning resources. The results outline how geospatial methods such as web cartography and geovisualization are highly useful in environmental education. User evaluations will review how various geovisualization techniques and interactivity play a role in engagement and learning capabilities.

KEYWORDS

Educational portal, web platform, interactive, visualization, Glenveagh National Park, Biodiversity, Geovisualization, Analysis

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This master's thesis has been composed by Ella Christie for the Erasmus Mundus Joint Master's Degree Program in Copernicus Master in Digital Earth for the academic year 2021/2022 at the Department of Geoinformatics, Faculty of Natural Sciences, Paris Lodron University Salzburg and Department of Geoinformatics, Faculty of Science, Palacký University Olomouc.

Hereby, I declare that this piece of work is entirely my own, the used references have been acknowledged and the thesis has not been previously submitted to the fulfilment of the higher degree.

A handwritten signature in black ink, appearing to read 'Ella Christie', with a stylized, cursive script.

06.05.2022 Olomouc, Czechia

Ella Christie

I would like to thank my supervisors, Alena Vondráková (Palacký University, Olomouc) and Barbara Scherthanner-Hofer (Paris-Lodron University, Salzburg), for their support and advice during the development of my research topic and over the duration of this project. I would also like to further thank Radek Barvír (Palacký University, Olomouc) for his support during the creation of the educational platform. Throughout the academic year, I have received unconditional support from my family, friends and colleagues. Their kind words and encouragement have kept me motivated from the beginning to the completion of this project, to which I owe them a debt of gratitude.

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ASSIGNMENT OF DIPLOMA THESIS

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Theses guidelines

The main goal of the diploma thesis is to analyze the available data on the biodiversity of wild species (the student will use the data from the cooperating reservations and open datasets) and then perform a suitable geovisualization of the analysis results and perform knowledge gained interpretation. The student will focus on the educational potential. The target group of created outcomes will be pupils, students, and the general public interested in the presented topic. The main aim is to introduce them to the biodiversity of wild species and enable them a more detailed study of selected geo-aspects. For this purpose, the student will create a website to share the structured outputs in the educational design with appropriate commentary.

The student will analyze existing data sources, select interesting topics, and design appropriate methods for geovisualization in the theoretical part. In the practical part, the student will prepare a set of geovisualizations with interpretations. The student will follow the principles of modern (carto)graphic design, including infographics. For topics where it is possible, the student will use Copernicus Data and Information Services. The main result of the diploma thesis will be a web page presenting a set of outcomes and geovisualizations on the selected topics with an educational focus. The student will attach all the collected datasets to the thesis in digital form. The student will create another simple website about the thesis following the rules available on the department's website and a poster about the diploma thesis in A2 format. The student will submit the entire text (text, attachments, poster, outputs, input and output data) in digital form on a storage medium and the text of the thesis in bound copies to the secretary of the department.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
CMYK	Cyan Magenta Yellow black (colour model)
GIS	Geographic Information System
HSV	Hue Saturation Value (colour model)
JPEG	Joint Picture Experts Group
RGB	Red Green Blue (colour model)
SHP	Shapefile
MMU	Minimum Mapping Unit
MMW	Minimum Mapping Width
GBIF	Global Biodiversity Information Facility
CLC	Corine Land Cover
EEA	European Economic Area
UK	United Kingdom
CLMS	Copernicus Land Monitoring Service
HTML	HyperText Markup Language
INSPIRE	Infrastructure for Spatial Information in the European Community

INTRODUCTION

National Parks provide a free and accessible space for the public to connect with nature. In return, an increased number of visitors brings more attention to the park, which can increase funding opportunities, support for protection and a source of income from amenities provided (Yang and Duan, 2020; Mayer, 2014). Finding new and innovative methods of engaging the public and garnering interest in National Parks and their wildlife is crucial to their upkeep (Weiler, Moore and Moyle, 2013).

National Parks play a vital role in environmental education, teaching visitors about local flora, fauna and ecosystems. Education is a powerful tool and critical in spreading the awareness of conservation issues from a local to global scale. In an ever-increasingly technological world, using virtual environments to increase knowledge and awareness of National Parks is highly useful. Online engagement enables a larger potential audience to be engaged with for outreach and education. Providing environmental education online also implies that even people who are unable to visit a National Park in person can still participate and be involved.

Biodiversity and Ecosystem data can be highly voluminous and complex. Spatial information is a core component of biodiversity data; for example, understanding where species are located in which environments and how they move through the landscape, or population change over time. This type of data must be condensed and represented in an engaging, comprehensible, and visually pleasing manner. Geovisualization is a set of tools and methods used in the synthesis, exploration, analysis and presentation of geospatial data to visualise information (Çöltekin, Janetzko, and Fabrikant, 2018; Kraak, 2009; Dykes, MacEachren and Kraak, 2005). It can showcase information that was previously not visible and involves concepts such as design, interactivity and publishing (Çöltekin, Janetzko, and Fabrikant, 2018). Geovisualization is a concept that aligns with environmental education as it similarly focuses on the user and how they engage with the information they are seeing.

This research analyses biodiversity data and applies geovisualization methods to the output, creating a web-based educational platform for potential visitors to Glenveagh National Park, Ireland. A brief species and habitat analysis will be conducted and visualized using geovisualization techniques to produce a series of educational resources, hosted on a website. The platform will contain a series of static and interactive maps plus educational activities and resources aimed at school-aged children. These resources will be available to download for families or school groups to complete at home, school, or take to Glenveagh National Park should they visit. The end-product will be user-tested to gain feedback and evaluate the effectiveness of applying geovisualization techniques to communicate biodiversity information. This report will detail the various steps and procedures involved in developing the educational platform and its materials.

1 OBJECTIVES

The main goal of the diploma thesis is to analyse the available data on the biodiversity of wild species and then perform a suitable geovisualization of the analysis results and perform knowledge gained interpretation. The student will focus on the educational potential.

The target group of created outcomes will be pupils, students and the general public interested in the presented topic. The main aim is to introduce them to the biodiversity of wild species and enable them to a more detailed study of selected geo-aspects. For this purpose, the student will create a website to share the structured outputs in the educational design with appropriate commentary.

The student will analyse existing data sources, select interesting topics and design appropriate methods for geovisualization in the theoretical part. In the practical section, the student will prepare a set of geovisualizations with interpretations. The student will follow the principles of modern (carto)graphic design, including infographics. For topics where it is possible, the student will use Copernicus Data and Information Services. The main result of the diploma thesis will be a web page presenting a set of outcomes and geovisualizations on the selected topics with an educational focus.

2 METHODOLOGY

The diploma thesis concepts were developed as follows.

Overview

The diploma thesis aims to create an open-source, educational web platform showcasing biodiversity and landscape data for Glenveagh National Park, Ireland. The platform will host a series of static and interactive maps, species profiles for local flora and fauna and educational activities for users to complete. The key focus of this research will be to use geovisualization methods and techniques to create an intriguing and user-friendly platform for potential park visitors with minimal requirements for technological expertise or biodiversity knowledge.

Goals

One of the main aims of this study is to create a fun and interactive web platform as a method of conservation education and environmental outreach, that can be utilised by users over a wide range of age groups and skillsets. Geovisualization will play a focal role in this project, producing easily interpretable and comprehensible information in a simple, user-friendly and enjoyable platform.

Subgoals

Delving into further detail, more specific objectives for this study are as followed:

(a) Collect and analyse open-source biodiversity data for twenty study species with recorded observations in Glenveagh National Park; (b) Use the processed biodiversity and landscape data to conduct a brief habitat analysis to produce a series of interactive and static maps; (c) use WordPress to develop and publish an easily accessible, open-source platform that is openly available to the public; particular attention is given to the design and geovisualization to enhance the appearance, usability and interactivity of the website; (d) develop a series of educational activities and additional resources available online and as downloadable pdfs relating to local flora and fauna and their surrounding landscapes; (e) Conduct user testing to gain feedback on geovisualizations and evaluate whether they aided in locating and retaining spatial information.

Conclusion

The output will demonstrate how an accessible and interactive platform built using geovisualization methods can be applied to environmental education. The hope is that demonstrating this method will act as a guide for National Park educational services and be further expanded upon in the future. Although the primary goal is education, the aim is also to generate interest in the National Park itself, encouraging visitors to use the knowledge they have gained online and apply it to their visits, such as navigational skills or wildlife identification. The results will allow school-age children to learn about local flora and fauna in a fun and interactive environment. Printable activities and maps will help teach about spatial awareness and local-scale conservation.

2.1 Used Data

CORINE Land Cover – 2018

The CORINE land cover dataset is a product of the Copernicus Land Monitoring Service (CMLS). The dataset utilises predominantly Sentinel 2 satellite imagery, supplemented by Landsat 8 imagery to produce a classification of 44 landcover types categorised into five broader habitat classifications for the entirety of Europe. This data set also incorporates change layers, producing a time series of landcover changes in Europe. CORINE landcover is open-source and available to download freely. CORINE is one of the CLMS' oldest datasets produced, the first dataset collated in 1990. High-resolution (<10m Sentinel 2) satellite images are used as a thematic base layer for the dataset. The CLC's technical parameters are MMU = 25 hectares and MMW = 100 metres. Participating countries in the CORINE dataset are currently 38 European Economic Area (EEA) countries and the United Kingdom (UK).

Irish Government – Glenveagh National Park SHP

According to Data.Gov.ie (2022), the dataset conforms to the INSPIRE directive, following all procedures and standards and was obtained by the National Parks and Wildlife Service, Department of Housing, Local Government and Heritage. The boundary map was produced using parcel data sourced from the Land Registry dataset from the Property Registration Authority of Ireland and the OSI PRIME 2 dataset. The polygon geometry was generalised to 50M to produce this map using the Simplify Polygon toolset (using the Wang-Muller algorithm method) in ArcGIS Pro 2.8 software.

Global Biodiversity Information Facility (GBIF)

GBIF is an open-source, government-funded, multi-nation approach to providing free and accessible biodiversity information online. There are 106 participating nations, organisations and governments contributing to this infrastructure. All data is collated and standardised following universal formats, structures and guidelines. GBIF provides a wealth of data on when and where a multitude of species have been recorded or observed. Key information such as the observation method, accuracy of coordinates and dates of observation are included.

MapCarta

According to MapCarta.com (2022), MapCarta is a web application that provides an easy, open-source method of viewing spatial data online using various sources. A sample of data sources used includes OpenStreetMap, GeoNames and MapBox. Mapcarta was applied in this project to explore the names and elevations of the various mountains within the Glenveagh National Park area and the names and locations of lakes, loughs and landscape features.

2.2 Used Methods

Existing open-source data will be obtained through online platforms and databases. Data will also be collected via survey to evaluate the end product. The biodiversity data will be processed and managed to display data the twenty study species and their observation records within Glenveagh National Park, along with global distribution. A brief habitat analysis will be conducted for the species observation data within the National Park.

Geovisualization is one of the focal concepts of this research project, utilising this method to engage users and create a visually pleasing educational platform to communicate environmental information. The term geovisualization is a shortened phrase coined from "geographic visualisation", referring to a set of tools and techniques applying design and visual concepts to communicate geospatial information. These methods can be applied across the various stages (exploration, analysis, synthesis and presentation) of producing or communicating geospatial data (Kraak, 2009). Geovisualization is a concept that was developed for interactive maps, which will play a vital role in this research topic. The tools and techniques involved within the umbrella term of geovisualization are primarily computer-based e.g. zooming in and out of a map or clickable features and pop-ups.

2.3 Used Software and Platforms

A wide variety of software will be used for the various aspects of this project. Although ArcGIS Pro and WordPress play the largest roles in the analysis and geovisualization stages, several other programs will be used to design resources, create interactive web maps and user test. Listed below are all of the software programs used for this project together with a short description of their role in the research study.

ArcGIS Pro

Version 2.9 of the desktop GIS software ArcGIS Pro was used to complete a variety of tasks, namely data processing and management, geospatial analysis and the initial stages of geovisualization. Tools such as the spatial join tool were utilised to combine datasets to make static global species distribution maps. ArcGIS Pro was also used to calculate species habitat preferences using GBIF occurrence data and Copernicus' CLC dataset.

ArcGIS Online

ArcGIS Online is a cloud-based ESRI product which enables users to store, share, analyse and create maps. All map layers created in ArcGIS Pro will be shared as web layers so that they will be accessible online to display as interactive maps in ArcGIS StoryMaps. ArcGIS Online will format the various maps with the uploaded layers to insert into the created StoryMap.

ArcGIS StoryMaps

ArcGIS StoryMaps is a web-based application which is used to present information in an interactive manner using various types of multimedia such as maps. An informative presentation on the history, wildlife, habitat and conservation of Glenveagh National Park will be created, including several highly interactive and visual maps created from the data processed in ArcGIS Pro.

Canva

Canva is a graphic design platform used to create visual content such as posters, documents and presentations. The educational resources and activities in downloadable PDF format will be designed and finalised on this platform.

Inkscape Project

Inkscape Project (version 1.1) will be used to create symbology for the Glenveagh species maps, both static and interactive. Inkscape is a software program for creating and designing vector graphics, therefore was ideal for creating customised symbology for this project. Six symbols are planned to represent the different biodiversity groups represented in the data, with a seventh being used for landmark features.

Mapbox

Mapbox is an online mapping service enabling users to create interactive web maps to be embedded into online platforms. It allows users to create datasets or upload data, as well as customise and design their maps to their preferences. Mapbox will be utilised to create the interactive maps included on the web platform for this project. Existing data processed in ArcGIS Pro will be uploaded and new datasets created in Mapbox to develop the interactive maps. Mapbox also provides a series of tutorials in Mapbox GLS (a JavaScript library for vector web maps).

Microsoft Excel

Microsoft Excel (MS Office 365) is utilised during the data processing and management stage of the research. Downloaded data must be refined and transformed to only show the required information.

Survey123

Survey123 is an Esri web application which enables the creation and design of forms and surveys to collect information. Data is automatically processed and analysed, removing the need for the creator to go through every individual response. Survey123 was used to conduct user testing for this study. The survey creator can use different design templates and colours and customise the format of answering questions e.g. dropdown boxes, scales, and written responses. A user-testing survey will be designed using this software and shared with several respondents along with a link to the educational platform.

WordPress

WordPress is an “open-source content management system” used to create websites. The educational website will be constructed using WordPress. A series of additional plugins will assist in the development of the platform including Elementor, Header and Footer and EmbedPress.

Visual Code Studio

Visual Code Studio is a source-code editor allowing users to create and edit code in several programming formats with debugging support provided. HTML programming was used to create and embed the interactive maps into the web platform. Visual Code Studio will be used to add features to the web maps and finalise them for publishing on the website.

2.4 Processing Procedure

Before beginning the analysis stage of this research project, it was imperative to further understand the topic and geovisualization methods, in addition to reviewing the various possibilities of software to use. Existing literature was extensively reviewed to clarify what is currently available online in terms of environmental education resources. Several tutorials were used to gain a better working knowledge of the selected software and platforms to ensure they were suitable for the project needs.

The acquired data was processed in ArcGIS Pro, particularly the species data, which was refined to within the National Park boundary and a sample selection of twenty species. CLC and geology data were used to conduct a brief analysis of the landscape characteristics. Analysis tools were then used to create layers showing the global distribution of the study species. In GeoJSON.io, geographical and landmark features were plotted to create a dataset for an interactive web map.

The visualization stage of the project had various sub-stages. Some design aspects were conducted in ArcGIS Pro, then layers were exported to ArcGIS online to create interactive maps and as GeoJSON files to be uploaded and visualized in Mapbox. HTML files were created to add clickable pop-ups to the web maps, embedded into the website. WordPress was used to create the educational web platform, including all the educational resources and maps. User-testing was then carried out on members of the general public and teachers for feedback and to evaluate the created platform and the user's ability to locate and retain biodiversity information where geovisualization techniques had been applied. A general workflow is pictured below in figure 1.

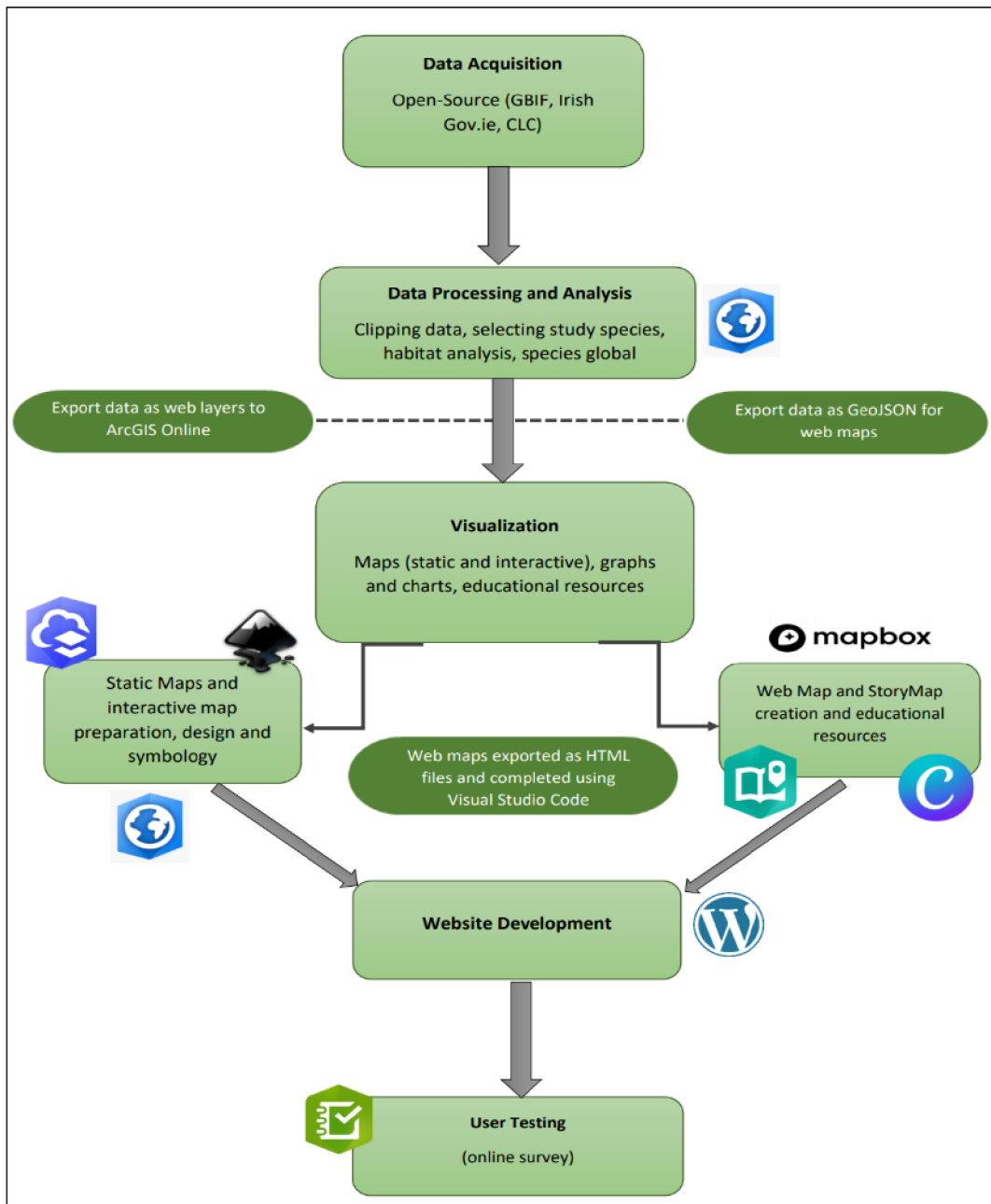


Figure 1: The scheme of the diploma thesis project

3 STATE OF ART

This chapter will use outline previous knowledge and research by evaluating various resources and materials relating to the research topic.

3.1 Principles of Geovisualization

Geovisualization is defined using a multi-disciplinary approach to develop both methods and toolsets for the exploration, synthesis, analysis and presentation of geospatial data visually (Çöltekin, Janetzko and Fabrikant, 2018; Kraak, 2009; Dykes, MacEachren and Kraak, 2005). Examples of the end product of geovisualizations include static maps, web maps and portals, and interactive maps. Maceachren's cartography cube (figure 2) changed the way people viewed geovisualization, taking a 3-dimensional approach, factoring in map use and the users themselves.

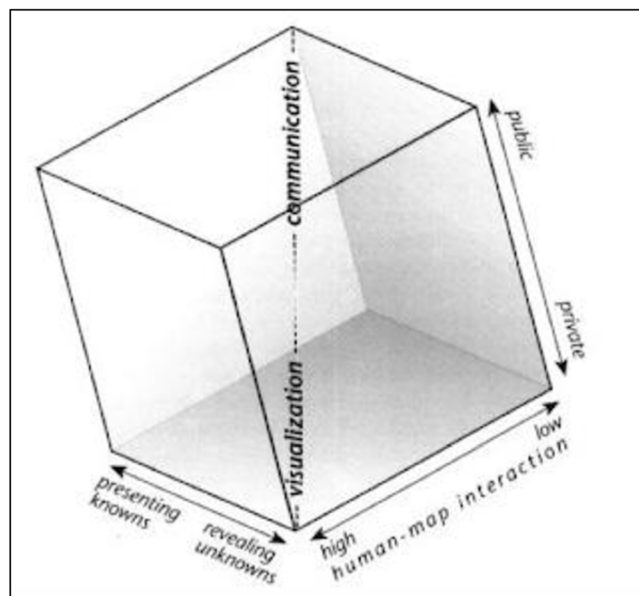


Figure 2: The cartography cube (MacEachren & Taylor, 1994)

Geovisualization offers a method of seeing the unseen, enabling the presentation of phenomena and features that aren't visible to the naked eye or immediately apparent in larger datasets e.g. population density or landcover change. Essentially, it can create various representations of large, complex datasets through methods such as cartograms, dasymetric mapping, or 3D visualisation (Longley et al., 2018). An important concept of geovisualization is understanding how the user interacts with the map. Human cognition and how people understand space and time greatly influence how they process and absorb information from maps (Nöllenburg, 2006). Therefore geovisualization systems should be tailored to the intended map audience.

3.2 Importance of Promoting and Protecting our National Parks

National Parks are one of seven categories of protected areas identified by the International Union for Conservation of Nature (IUCN), ranging in levels of protection and management. National Parks are listed as category two, defined as “*Large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.*” (IUCN, 2022). Their emphasis is on maintaining a healthy ecosystem for a wide range of biodiversity and encouraging visitors to boost local tourism. National Parks provide the public with an opportunity to reconnect with nature in an increasingly urbanising world. Engaging with natural habitats and biodiversity is crucial for gaining and maintaining public support for conservation. Public interest is one of the driving factors behind the maintenance and preservation of National Parks (Siikamäki et al., 2015; Eagles et al., 2002). Without public support, these areas risk being redeveloped by governments for other purposes. Although human presence in natural areas can often have negative connotations, the relationship between the public and biodiversity in National Parks can be mutually beneficial. Visitors are attracted by the preserved natural landscapes and wildlife, while designated trails and tracks control human disturbance. Visitors provide revenue for conservation projects and park upkeep (Atiqul Haq, 2016). Nevertheless, finding balance is essential; tourism must be managed so that ecosystems within National Parks can be conserved.

3.3 Environmental Education Web Platforms

Technology is incorporated into our daily routines, especially in education and school systems, where interactive and virtual learning is the norm (Barak and Ziv, 2013). Web platforms have a plethora of potential uses. Environmental education plays a key role in conservation. Digital platforms can reach a global audience, greatly increasing access to resources, information and learning tools (Balabanova et al., 2021). Nevertheless, environmental education is more effective in an immersive environment e.g. an outdoor setting (Kamarainen et al., 2013; Chang, Chen and Hsu, 2011). Amalgamating an online platform with activities which would encourage presence in a natural area would be highly beneficial for school-age students.

Examples of existing resources and platforms:

1) National Parks UK – Teaching resources

The National Parks UK website provides a series of downloadable pdf maps and information sheets about their parks and history. They are well-structured and contain static maps to show spatial data, nevertheless lack geovisualization and design concepts to make them more appealing to their audience.

2) Yellowstone National Park – Distance learning resources

Yellowstone National Park also provides a webpage with downloadable resources on a number of environmental topics. Although informative they lack any form of design, especially because they are made for school age students. Use of colour, images and infographics would help engage the intended audience.

3) Park Online Resources for Teachers and Students (PORTS) – California state parks

California state parks provide a digital library with a wide range of activities available including downloadable resources, Youtube videos, virtual learning with park rangers and virtual field trips through the parks. This provides several learning options for students with different levels of interactivity.

4) GISLEKCE – Katedra Geoinformatiky - Petra Hujňáková

The most similar project was created by Petra Hujňáková (Palacký University, Olomouc) in which teaching materials through step-by-step tutorials, videos and other online resources aimed at secondary schools were provided in a well-designed web platform.

Environmental education resources are relatively easy to find online, many of which open-source. Nevertheless, none of the resources found incorporated interactive maps as an educational tool, and many were greatly lacking in visualization. This research topic aims to create more interactivity on the educational platform to attract potential visitors. Educational resources aimed at school age children will incorporate geovisualization methods such as colour, typography and infographics to enhance viewer interest.

Analysing and visualising Biodiversity Data

As previously discussed, geovisualization enables large and complex datasets to be presented in a more easily interoperable manner (MacEachren and Kraak, 2001). Rapid technological advances in the 21st Century have triggered a rise in digitizing the collection and analysis of biodiversity data, leading to large, often open-source data sets being made accessible online (Nelson and Ellis, 2018). A prime example is GBIF: an open-source online database of biodiversity records used for this research project. On a national scale, portals such as the National Biodiversity Data Centre, run by the heritage council in Ireland, enable users to freely explore biodiversity data to learn more about species distribution of various species.

Geospatial data is a crucial component of biodiversity information. Locational data can show habitat preferences, population distribution, or predict where unknown populations of species of interest may be (SALEM, 2003). Often, further environmental factors need to be assessed to understand biodiversity patterns, including climate, precipitation and soil pH, which are obtained using geospatial techniques. Incorporating geovisualization methods into the analysis and visualization of biodiversity data would be highly effective in communicating vital information, particularly to users who may not have background knowledge of the area.

Examples of Visualizing Biodiversity data:

1) OneZoom – Tree of Life

This web platform was developed to use dynamic visualization through animations and interactivity to show the complete tree of life. Users can explore the tree and click on branches to see the relationships between species and their hierarchies (Wong and Rosindell, 2021).

2) Biodiversity Indicators Partnership – Dashboard

This dashboard is designed specifically to cater to the user, providing an interactive platform to explore visualized biodiversity datasets, which have been used to monitor the progress of the Aichi biodiversity targets. Users can view data by country or by biodiversity indicator or target and compare the progress between different nations in meeting their goals. The interactive map is supported by graphs and charts, providing further figures.

3) antmaps.org

antmaps.org is the interactive visualization of the global distribution of all ant species. Users can search by species richness, and individual species ranges, or compare species diversity and richness by region, even displaying which areas have similar ant distributions and species diversity (Janicki et al., 2016). The map is highly interactive with nice use of colours to distinguish data, the user can hover over regions to gain further information and click on a region for a complete species list.

There are many examples of utilising geovisualization in the analysis and visualization of biodiversity data. Many of these examples involved interactive maps to explore the data, with a variety of geovisualization techniques used. They act as useful resources to refer to for this study, helping to gain a broader understanding of the numerous methods that can be incorporated to provide a user-friendly interactive platform.

4 BIODIVERSITY DATA ANALYSIS

The following chapter will detail all procedures relating to the collection, processing, and analysis of the obtained biodiversity and related data. An insight into the selected study area is also provided. The steps conducted in this investigation are depicted in sequential and chronological order, from obtaining the required data to the final output of the analysed data.

4.1 Study Area

The selected study area for this project is Glenveagh (Gleann Bheatha) National Park, Donegal, Ireland (figure 3). Its name, translated from Irish Gaelic, means valley of the birches, referring to birch trees. Glenveagh is one of six designated National Parks in Ireland, covering approximately 170km². Within the park lies most of the Derryveagh mountain range, the tallest peak being Errigal at 751m. Landcover types in Glenveagh can be organised into four broad categories: upland, peatland, woodland and freshwater. Upland habitat is dominated by exposed and sparsely vegetated rocky ground where soil quality is often low, and Arctic alpine species thrive. Peatlands are waterlogged habitats in which a dense peat layer (at least 30cm thick) sits on the surface, formed from organic material which has not fully decomposed. They are a natural carbon store, therefore a crucial habitat to preserve. Ireland is home to a large proportion of the world's blanket bog habitat. This habitat hosts a wide variety of species from insects to wetland birds and unique plants such as bog cotton.

Glenveagh National Park contains several lakes ranging in size, the largest being Lough Veagh, at approximately 6km long. The freshwater habitat within Glenveagh is unique as all of the water sources that run into the lakes fall within the park boundaries. Therefore, it is possible to prevent them from being polluted. Several rare and endangered species reside in Glenveagh's freshwater habitat, including the freshwater pearl mussel, salmon and Arctic charr. The red-throated diver also utilises these habitats and nests nearby, the only location in Ireland where these diving birds breed. A small proportion of Glenveagh's landscape consists of natural and semi-natural woodlands. This is prime habitat for rare mosses, ferns and other woodland creatures.

Glenveagh is protected by EU law, as it falls within the Cloghernagore Bog and Glenveagh National Park Special Area of Conservation (SAC) due to its distinctive habitats and biodiversity (NPWS, 2017). The unique habitats and species causing this designation are listed below (Table 1). Glenveagh (Fig. XX) was selected as the chosen study site as its biodiversity and landscape is completely unique to the west of Ireland, unlike the other National Parks in Ireland. A diverse range of species, particularly ones which are rare to Ireland or under-threat are ideal study species for environmental education

Table 1: Protected and important species and Habitats within Glenveagh National Park

Habitat/Species of Interest	Natura 2000 Code
Oligotrophic waters containing very few minerals of sandy plains (<i>Littorelletalia uniflorae</i>)	3110
Water courses of plain to montane levels with the <i>Ranunculus fluitantis</i> and <i>Callitriche-Batrachion</i> vegetation	3260
Northern Atlantic wet heaths with <i>Erica tetralix</i>	4010
European dry heaths	4030
Alpine and Boreal heaths	4060
<i>Molinia</i> meadows on calcareous, peaty or clayey-silt-laden soils (<i>Molinia caerulea</i>)	6410
Blanket bogs (* if active bog)	7130
Depressions on peat substrates of the <i>Rhynchosporion</i>	7150
Old sessile oak woods with <i>Ilex</i> and <i>Blechnum</i> in the British Isles	91A0
<i>Margaritifera</i> (Freshwater Pearl Mussel)	1029
<i>Salmo salar</i> (Salmon)	1106
<i>Lutra</i> (Eurasian Otter)	1355
<i>Trichomanes speciosum</i> (Killarney Fern)	1421

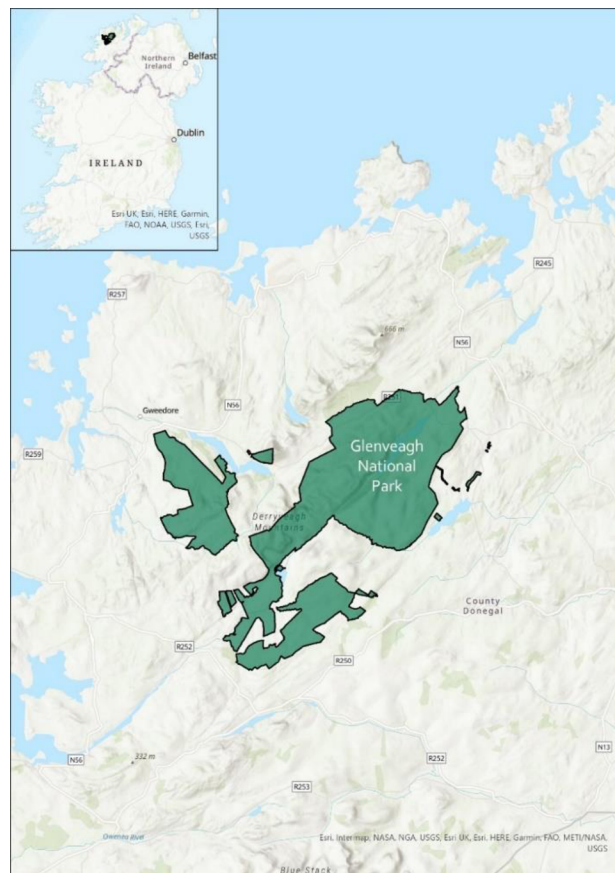


Figure 3: Glenveagh National Park Outline

4.2 Data Collection

All data obtained and used in this research are from open-source databases from accredited organisations/bodies which have Creative Commons 4.0 (Attribution 4.0 International - CC BY 4.0) licenses. Under this license, users are able to copy and redistribute the data provided as well as alter or modify the dataset (Creative Commons, 2022). The only condition for this license is that the data source must be appropriately credited. Four groups of datasets were accessed for this study: Glenveagh National Park Boundaries, Landcover classification data, bedrock geology and Biodiversity data.

4.2.1 Glenveagh National Park Boundaries

The Glenveagh National Park boundary SHP was obtained from the Irish government's open data portal. The specifications of the dataset are provided in table 2 below (Ireland's Open Data Portal, 2022).

Table 2 – Specifications of Glenveagh National Park SHP

Published by	Department of Housing, Local Government and Heritage
Last Updated	22-02-2022
Standards Compliance	INSPIRE directive
Reference System	Irish Transverse Mercator
Data Source	Parcel data from Land Registry dataset and OSI PRIME 2 datasets
Technical Specifications	Polygons generalised to 50m using Simplify Polygon toolset (ArcGIS Pro 2.8)

4.2.2 Corine Landcover Dataset (2018)

Copernicus' Land Monitoring Service is responsible for the production and maintenance of a European landcover dataset known as CORINE land cover. The data is available to download as a 100m GeoTiff, Esri Geodatabase and SQLite Database. The specifications of the downloaded dataset are exhibited in table 3 (Copernicus Land Monitoring Service, 2022).

Table 3– Specifications of CLC dataset

Published by	Copernicus Land Monitoring Service
Format	Vector – Esri Geodatabase (5gb)
Last Updated	2018
Satellite Data	Sentinel 2, Landsat 8
Geometric Accuracy	≤ 10m (Sentinel-2)
MMU/MMW	25 ha / 100m
Broad Classifications	5 (artificial surfaces, agricultural areas, forest and seminatural areas, wetlands and water bodies)
Classes	44

4.2.3 Ireland Geology Dataset

Similarly, to the Glenveagh National Park boundary SHP, the Ireland bedrock geology SHP was obtained from the Irish government's open data portal. The specifications of the dataset are provided in the table (4) below (Ireland's Open Data Portal, 2022).

Table 4: Specifications of Ireland bedrock geology SHP

Published by	Geological Survey Ireland
Last Updated	22-10-2021
Standards Compliance	INSPIRE directive
Reference System	Irish Transverse Mercator
Data Source	“Geologists map and record information on the composition and structure of rock outcrops (rock which can be seen on the land surface) and boreholes (a deep narrow round hole drilled in the ground). Areas are drawn on a map to show the distribution of rocks”
Technical Specifications	Scale 1:100,000 (made using 21 maps of this scale covering Ireland)

4.2.4 GBIF Species Observation Records

GBIF is the creator of the largest open-source database for biodiversity observation records. The datasets required for the investigation can be sub divided into two groups: observation data for all species within Glenveagh National Park and individual global distribution for the 20 selected study species. The specifications of the dataset for all species observations within an approximate area of Glenveagh National Park are shown in table 5.

Table 5: Specification of GBIF species dataset

Dataset Citation	GBIF Occurrence Download https://doi.org/10.15468/dl.49wjen
Format	CSV
Number of Observations	5,397
Number of Species	1015
Dataset Parameters:	
Occurrence Status	Present
Basis of Record	Human Observation/preserved specimen
Location	Glenveagh National Park (approx. polygon drawn), including coordinates
Year	1980-present

For each of the 20 study species, a global distribution map of their population spread is to be created. To do this, individual datasets for each study species needed to be obtained using different parameters to the Glenveagh data set which. Attachment 1 depicts the downloaded database information for each species.

4.3 Data Processing and Management

The obtained data listed in the previous sub-chapter required processing to better understand and refine its contents. 20 sample species were selected to represent this study, reduced from 1,015 species (including fungi). On the GBIF platform, data can be narrowed to a country, or the user can draw an area on a map in which they wish to view species observations. Due to this feature, an approximate area around Glenveagh National Park was drawn as opposed to its exact boundaries. Therefore, the data needed to be transformed to display species observation records within the park's official boundaries. Firstly, the CSV file is added to a Microsoft Excel worksheet for the data contents to be reviewed. At this stage, the table was refined to reduce the file size and ease the location of important information. The file was subsequently exported in CSV format for the second stage of processing in ArcGIS Pro.

GIS software was used to conduct the majority of data processing and management. The Glenveagh National Park shapefile was added to a new map in ArcGIS Pro and the define projection tool was used to convert the projection from Irish Transverse Mercator to WGS 84. The decision was made to use this projection for all maps as the majority of the created maps were designed to be world maps.

Furthermore, Mapbox web maps is this projection by default and all other data collated used this projection. The CSV file containing the rough species data was added as a table to the map, using the ‘display X, Y data’ option to add the records as points on the maps. Some of the records lay outside the park’s boundary. The clip tool was subsequently used to create a layer showing only the species’ observations within Glenveagh’s boundary.

The final stage of transforming the Glenveagh species involved refining the remaining data to a sample of 20 selected species. Microsoft Excel provided the best platform to explore the data as a table. The clipped layer was exported as an .xl table using the table to Excel tool in ArcGIS Pro. 918 species remained, including fungi, which were later removed. Study species were selected based on background research into conservation interest within the National Park, native species significant to Ireland and some commonly known and beloved species. The aim was to represent a broad range of flora and fauna to showcase the diversity within the park. A list of species was compiled and compared with the available species data. Species including salmon, Killarney Fern and Artic Charr were originally selected as potential study species however no data was available. A complete list of the twenty study species is provided in table 6.

Table 6: Selected study species for thesis project

Birch (<i>B. pubescens</i>)	Bog Cotton (<i>E. angustifolium</i>)	Common Frog (<i>R. temporaria</i>)	Eurasian Curlew (<i>N. arquata</i>)
Devil’s-Bit (<i>S. pratensis</i>)	Eurasian Bullfinch (<i>P. pyrrhula</i>)	Eurasian Otter (<i>L. lutra</i>)	Eurasian Pygmy Shrew (<i>S. minutus</i>)
Freshwater Pearl Mussel (<i>M. margaritifera</i>)	Golden Eagle (<i>A. chrysaetos</i>)	Heather (<i>C. vulgaris</i>)	Irish Hare (<i>L. timidus hibernicus</i>)
Irish Stoat (<i>M. erminea hibernica</i>)	Lindenberg’s Featherwort (<i>A. lindenbergianus</i>)	Long-eared Owl (<i>A. otus</i>)	Red Deer (<i>C. elaphus</i>)
Red Squirrel (<i>S. vulgaris</i>)	Red Admiral Butterfly (<i>V. atalanta</i>)	Red Throated diver (<i>G. stellata</i>)	White-tailed Bumblebee (<i>B. locorum</i>)

The CLC dataset is unable to be refined to a particular country or region when downloading. Landcover data was only required for the Glenveagh area, therefore the CLC vector data was added to a map in ArcGIS Pro and the clip tool was used to create a new landcover dataset refined to Glenveagh National Park using the boundary SHP (figure 4). The CLC is projected as 'ETRS89_LAEA_Europe' which needed to be reprojected to WG84 using the defined projection tool in ArcGIS Pro.

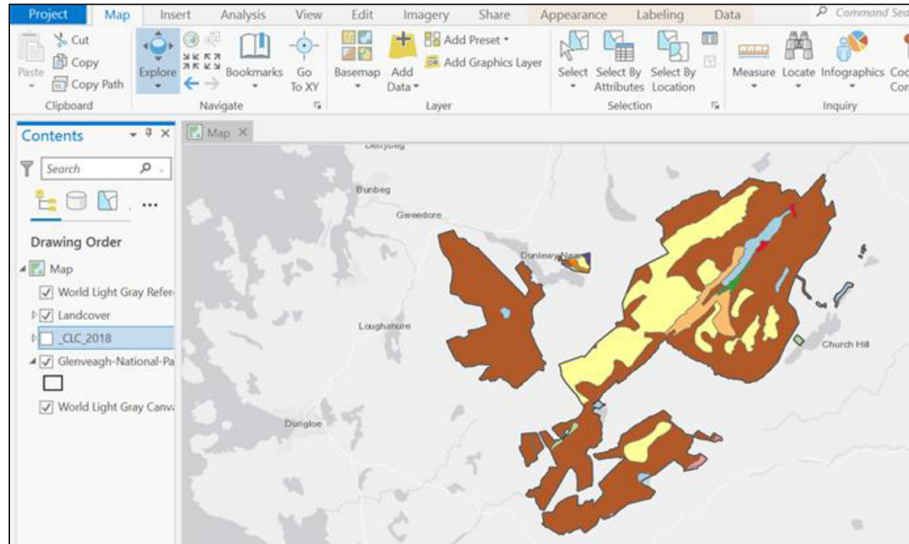


Figure 4: Analysis - Clipped CLC data to Glenveagh National Park

Similarly, to the CLC dataset, Ireland's bedrock geology data also required refining to only show relevant information for Glenveagh National Park. The clip tool was used to cut the geological data to the park boundaries (figure 5).

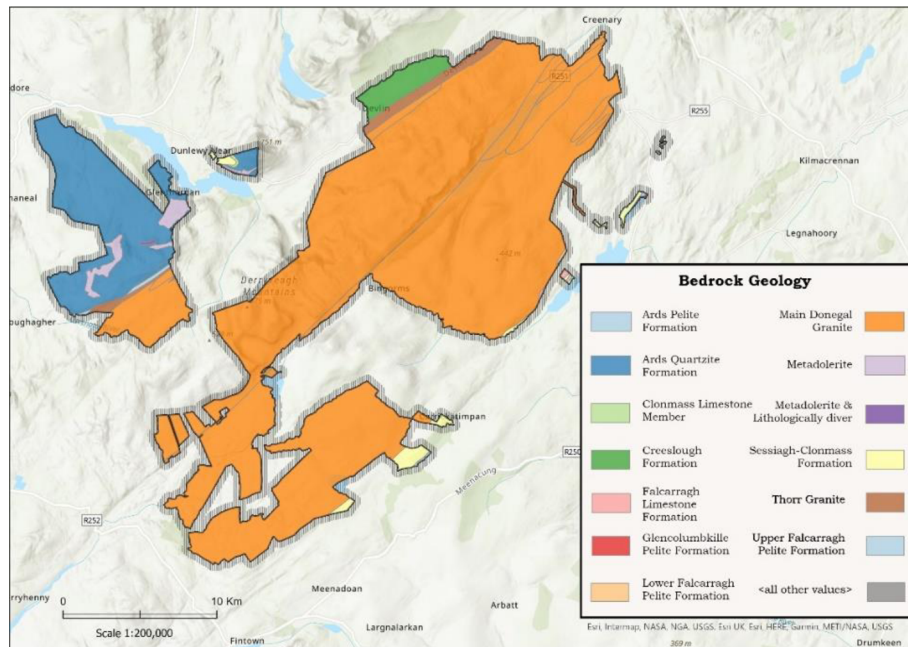


Figure 5 – Map of the Geology of Glenveagh National Park in ArcGIS Pro

4.4 Data Analysis

4.4.1 Global Distribution of Species

A species profile was designed and created for each of the 20 study species selected to represent wildlife in Glenveagh National Park. The aim is to include a static map on each of the profiles showing the global distribution of each species by visualising which countries they have been observed in. The created layers are intended to be further utilised to create an interactive global distribution map on the StoryMap presentation. This sub-section will detail the process of analysing and transforming data to produce the global species distribution maps. Individual maps were created for each species so the following steps were repeated for all 20.

As detailed in previous chapters, GBIF was used to create and download the observation records for each species with no parameter set for a location. The CSV file was added into ArcGISPro as a standalone table, selecting the option to ‘display XY data’ to create a new layer of species observations on the map (figure 6).

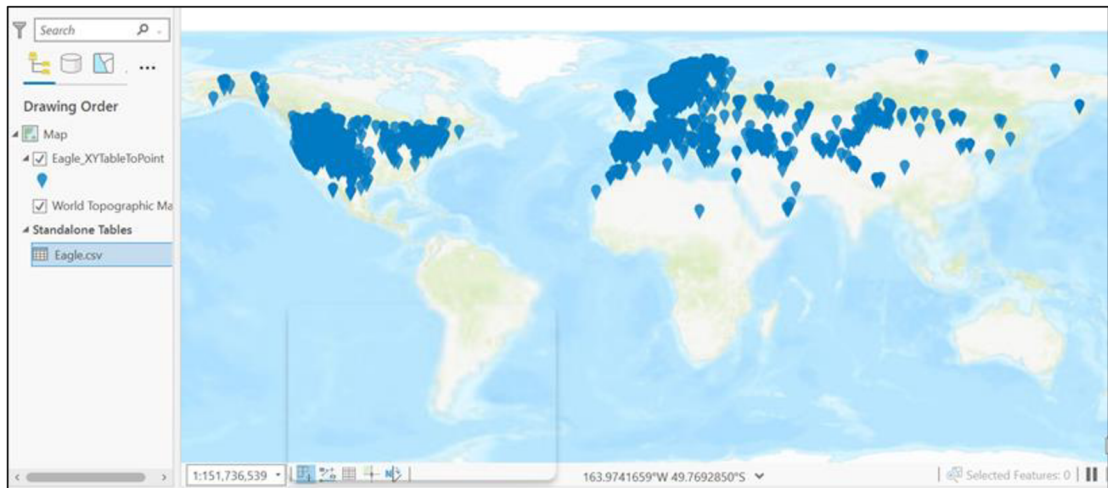


Figure 6: Analysis- Global distribution of Golden eagles' observations

A layer called ‘World Countries_(Generalized)’ was added to the map from ArcGIS Online to provide a polygon layer of world countries to be used in the analysis. To visualise in which countries the species had been observed, the ‘Spatial Join’ tool was used. The parameters were set to produce a layer showing only the countries where recorded observations were found completely within the country’s boundary. The output to be visualized is the original layer containing polygons of all world countries and the spatially joined polygon layer displaying the species distribution.

The next stage was carried out for the interactive maps to be used in the presentation. The number of observations per species worldwide is numerous, most reaching into the thousands or even hundreds of thousands. This was causing the map to look highly cluttered and making it difficult to process the data being shown. To combat this, the aggregation tool in ArcGIS Pro was used to display the point data in clusters. The advantage of this is that the clusters are scalable, meaning they change size the further in/out you scroll on the map, showing more detailed clusters the further zoomed in the user scrolls (figure 7). This was chosen as an ideal geovisualization technique to communicate more detailed information about the species' observations.

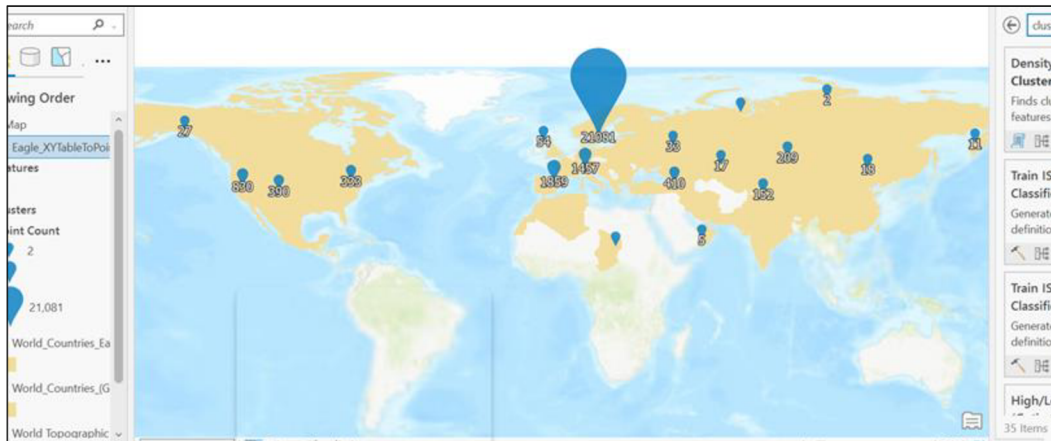


Figure 7: Analysis - Clustering global species observations (Golden eagle)

4.4.2 Habitat and Species Analysis

Habitat analysis was conducted to better comprehend the landscape dynamics and characteristics of Glenveagh National Park. Land cover data provides detailed information about the composition of a landscape. Habitat type is dependent on numerous climatic and environmental factors, including temperature, precipitation, elevation and geology. It is a determining factor in the type of biodiversity that inhabits these areas. Similarly, geology impacts the type of land cover which grows on it, in turn, the biodiversity which inhabits there. Geology can influence biodiversity both directly and indirectly. The physical characteristics of the rock can directly influence biodiversity through its shape (topography), elevation and slope; indirectly, geology determines which soil and substrate grow on top of it due to factors such as varying mineral content, erosion rates and water absorption (English Nature, 2022).

381 species observations were recorded within Glenveagh National Park from the 20 study species. Notably, nearly half of the observations were from the white-tailed bumblebee, likely due to surveys being done on or near their hives. The Eurasian otter was recorded 36 times while red deer were recorded on 19 occasions. Lindenberg's featherwort has been recorded only three times, as has the Eurasian pygmy shrew. A list of the specific frequency of observations is provided in table 7.

Table 7: Species Frequency in Glenveagh National Park

Species	Frequency
Birch	4
Bog Cotton	4
Common Frog	4
Curlew	4
Devils Bit	3
Eurasian Bullfinch	23
Eurasian Otter	36
Eurasian Pygmy Shrew	3
Freshwater Pearl Mussel	4
Golden Eagle	8
Heather	13
Irish Hare	11
Irish Stoat	18
Lindenberg's Featherwort	3
Long-eared Owl	5
Red admiral Butterfly	17
Red Deer	19
Red Squirrel	9
Red-throated Loon	14
White tailed Bumblebee	179
Total	381

Two open-source datasets were used to conduct the habitat analysis; Corine landcover data and bedrock geology of Ireland. The specifications and contents details of both of the data sets used are described in sub-chapters 4.4.2 and 4.4.3 respectively. Both datasets required processing to refine the information shown to Glenveagh National Park specifically. The procedure for this is outlined in section 4.3. The two datasets were analysed using the species observation dataset for Glenveagh National Park to gain more perspective on the various landscape influences on species distribution. The same analytical procedure was conducted for both the land cover data which is described as follows. The buffer tool was used set to a distance of 200 metres around each of the species' observations (figure 8). Following this, the pairwise intersect tool was used to conjoin the species data with the CLC data using the created buffers and each landscape dataset individually.

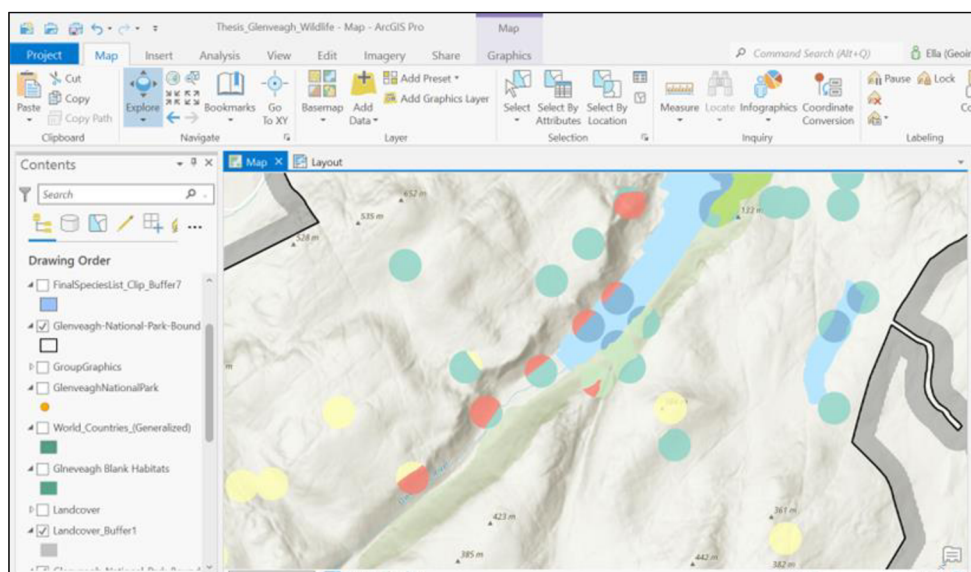


Figure 9: Pairwise Intersect – Land cover data with created species buffer

The geological make-up of the National Park was further analysed to better understand the influencing factors behind the land cover type. This was carried out to gain further insight into the landcover and geological make-up of the immediate surrounding area to species observations. To quantitatively assess the output of each of the intersected datasets, the summarize tool was utilised to create a series of tables to calculate to total and mean areas (m) of bedrock type and landcover type per species. Further tables were also created for comparison assessing the complete geological and landcover make-up of Glenveagh National Park. The tables were then able to be assessed to evaluate variations in geological and habitat make-up per species. Each of the created tables was converted to an excel document (. xl) format and exported from ArcGIS Pro. To further visualize this data and make it easier to establish patterns, several graphs and charts were created using the created tables in Microsoft Excel.

Fourteen total land cover types out of the 44 classifications within the CLC dataset were detected within Glenveagh National Park (figure 9). Ten habitats contained species observations: only three of which in large proportions. Peat bogs covered the largest area, making up 38% of the park's habitat. Water bodies and mixed forest were the other two, covering 15% and 35% respectively.

The remaining land cover types ranged from 0.03% - 5%, with the lowest area coverage being pastures and the largest sparsely vegetated areas. A pie chart showing the land cover composition of areas with species observations is provided in figure 10.

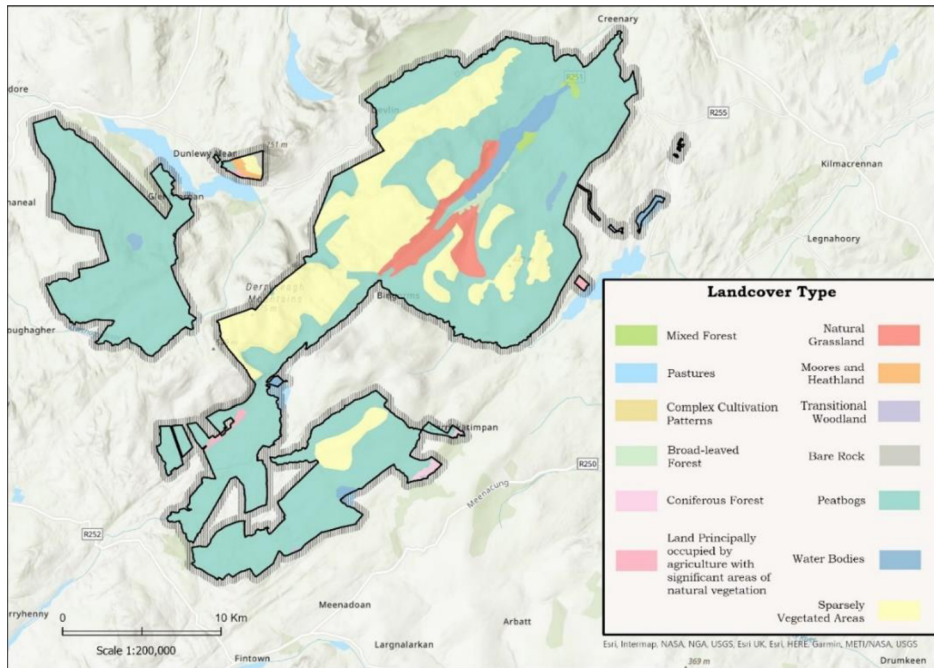


Figure 9: Map of Landcover Type in Glenveagh National Park

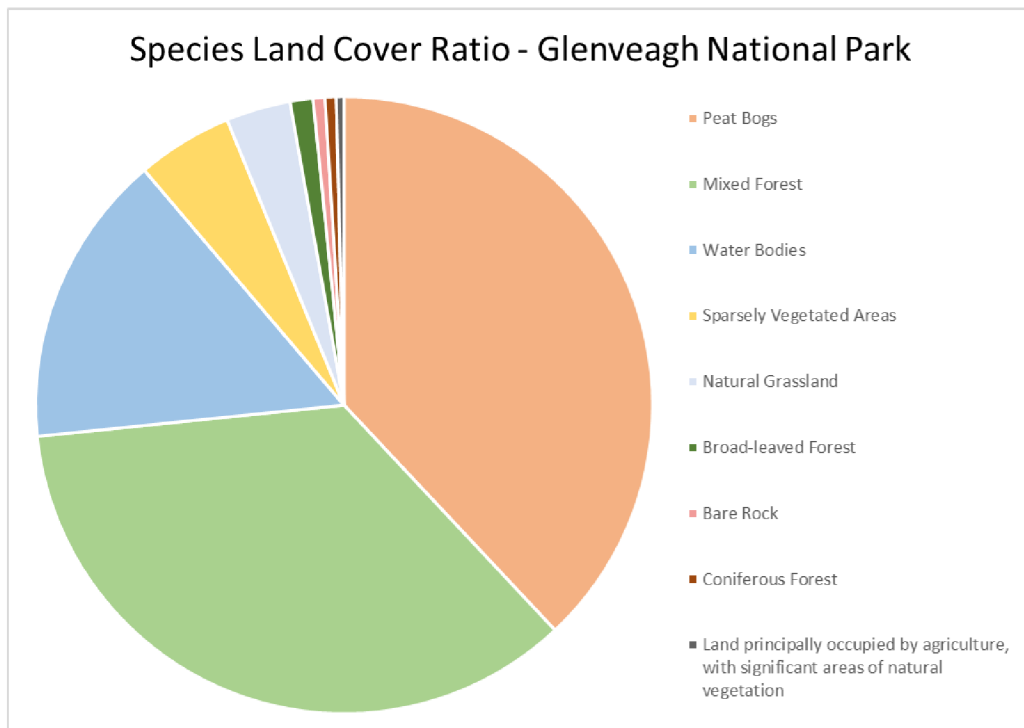


Figure 10: Pie chart showing land cover area in Glenveagh National Park

Statistics were carried out on species observations within each habitat to determine the number of species present in each land cover type. As expected the three largest habitats had the most species present. All twenty of the study species were recorded in peat bog habitats, whereas 15 were recorded within a short distance of water bodies and 11 within mixed forest habitats. Despite having the lowest percentage of land cover (0.03%), five species were recorded around pasture habitats. Both coniferous forest and land principally occupied by agriculture, with areas of significant natural vegetation only recorded one species each respectively. The full breakdown of species presence per habitat is depicted in Attachment 2. An example of land cover make-up for individual species is provided in figure 11.

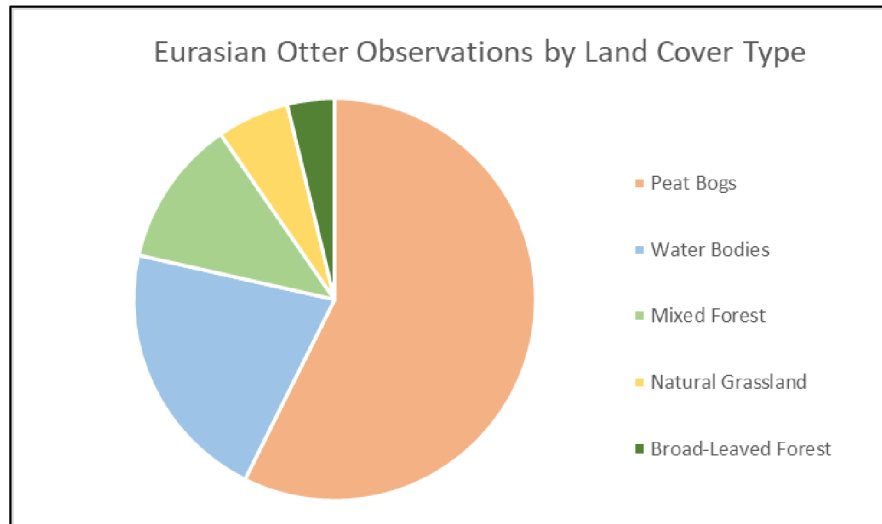


Figure 11: Pie chart showing habitat composition of otter observations

Thirteen geology types were documented within Glenveagh National Park. Nevertheless, a total of 81% of the area of Glenveagh National Park consists of main Donegal granite. A further 12% of the area is Ards quartzite formation. The remaining geology types range from 0.04% to 2% of coverage within the park (Table 8).

Table 8: Geology type by percentage of coverage in Glenveagh National Park

Geology Type	Total % Area
Ards Pelite Formation	0.14
Ards Quartzite Formation	12.36
Clonmass Limestone Member	0.04
Creelough Formation	1.99
Falcarragh Limestone Formation	0.08
Glencolumbkille Pelite Formation	0.02
Lower Falcarragh Pelite Formation	0.03
Main Donegal Granite	81.11
Metadolerite	1.24
Metadolerite & Lithologically diver	0.04
Sessiagh-Clonmass Formation	1.14
Thorr Granite	1.70
Upper Falcarragh Pelite Formation	0.09

5 GEOVISUALISATION

In this chapter, the stages and processes of design and geovisualization of the end product are documented and discussed in detail. It has been divided into five sub-chapters categorising the various products created which have then been further sub-divided into specific features. A step-by-step procedure for the creation, design and publishing of each component is provided, supplemented with technical specifications and some discussion of the decision-making process.

5.1 Symbology

This sub-section will outline the process of creating customized symbology for the various interactive maps to be published on the educational platform. Inkscape was the chosen software to create symbology for this project.













5.1.1 Glenveagh Species Map

A map of Glenveagh National Park containing observation records of the 20 study species was created to be published as a web map, showing both as an interactive map on the educational platform and in the StoryMap presentation. Using a different symbol for each of the individual species could confuse or overwhelm users, therefore, it was decided to create broad classifications instead. The 20 species were divided into six groups:

- Mammals
- Birds
- Amphibians
- Plants
- Freshwater
- Insects

The aim was to create similar and uniform symbology which would identify each group and be aesthetically pleasing for the user. Seven icons relating to each category were obtained from SVG repo (svgrepo.com) (two icons were amalgamated to make one symbol). In Inkscape, the 'create circle' tool was used to make two circles, one larger, the second centred inside. The circle colours were designed to be lighter on the inside circle and darker on the outside. The icon was placed in the centre of the created marker, and the three layers were grouped. A full specification of the created symbology is shown in table 9, as the icons were white, the row has been shaded in light grey. Each of the six created symbols was exported in SVG format and subsequently added as new symbology into ArcGIS Pro and Mapbox.



Table 9: Species symbology specifications

Specifications	Symbol					
	Mammal	Bird	Plant	Amphibian	Insect	Freshwater
Icon						
Icon size (px)	390×340	270×430	250×420	310×300	300×350	330x350
Icon Colour (RGB)	255,255,255	255,255,255	255,255,255	255,255,255	255,25,255	255,255,255
Inner Circle Size (px)	450×450	450×450	450×450	450×450	450×450	450×450
Inner Circle Colour (RGB)	255,170,0	190,230,255	0,140,75	155,100,0	255,210,245	0,80,170
Outer Circle Size (px)	500×500	500×500	500×500	500×500	500×500	500×500
Outer Circle Colour (RGB)	240,120,20	115,220,255	20,110,60	115,40,0	255,190,230	0,40,115
File format	SVG	SVG	SVG	SVG	SVG	SVG
Final Product						

5.1.2 Glenveagh Features

Custom symbology was also created for the interactive web map showing the various landscape features and landmarks in Glenveagh National Park. The symbol's purpose was to draw the user to click on them to activate the clickable map popups. A binocular icon was selected for the theme as a way of communicating that the symbols represented places to see. The steps in the creation of this symbology were almost identical to the species symbology so it is repeated in the text, nevertheless, the full specifications are provided in table 10 below.

Table 10: Glenveagh features map symbology specifications

Specifications	Symbol
Icon	
Icon size (px)	390×290
Inner Square Size (px)	450×450
Inner Square Colour (RGB)	255,235,100
Outer square Size (px)	500×500; square rounding 10%
Outer Square Colour (RGB)	255,210,0
File Format	SVG
Final Product	

5.2 Static Maps – Global Species Distribution

Section 4.1.1 outlined the creation of the global species distribution maps. This section relates solely to the design and geovisualization of the static maps for the species profiles. An example using the golden eagle will be continued from the analysis chapter, as all 20 maps were designed in the same format. Before customizing the species distribution maps, some design considerations were taken into account. Firstly, and most importantly, the map audience. Although intended to be enjoyed by everybody, the species profiles were catered to children and young people. This led to the conclusion that the map should not be overcomplicated, which also translated to the design principles. The aim was to make good use of colour, clear boundaries and labels. The second consideration is that the map must aesthetically align with the species profile design itself e.g., no clashing colours.

ArcGIS Pro was used style both the world countries polygon layer and the layer of countries with species observations occurring. Two additional styles were downloaded externally from Esri styles (<https://esri-styles.maps.arcgis.com/>): Firefly and Imhof. The 'Reverse AOI simple' style was selected for the world countries layer, which gave the base some definition between country borders and a slight shadow effect. Although the species profiles are viewable online, they are also available as printable PDF documents, therefore, the layer was designed using the CMYK colour model. There are three layers in this style: solid stroke, gradient stroke and a solid fill. The solid stroke and fill were

formatted to display as green with a yellow/beige outline to provide more boundary definition and produce a small glow effect without detracting from the species observation layer.

- Solid Fill – CMYK – 100 – 30 – 50 – 20 – 50
- Solid Stroke – CMYK – 10 – 10 – 25 – 5

Ensuring that the polygon layer displaying the species' presence in a country stood out to the user and was easy to identify was paramount. For this layer, the Firefly style 'FireflyPolyInner_18' was used which creates a bright glow effect around boundary lines by using several solid stroke layers. The bright orange colour stood out clearly against the green background, making it easy to identify which countries the species has been recorded in (figure 12). Nevertheless, the colour was adjusted slightly to increase the contrast between the fill and outlines using the CMYK colour model. The exact specifications are as follows:

- Solid Stroke – CMYK – 0 – 0 – 0 – 0
- Solid Stroke – CMYK – 0 – 30 – 75 – 0 – 60
- Solid Stroke – CMYK – 0 – 30 – 85 – 0 – 85
- Solid Stroke – CMYK – 0 – 30 – 85 – 0 – 85
- Solid Fill – CMYK – 0 – 30 – 85 – 0 – 80

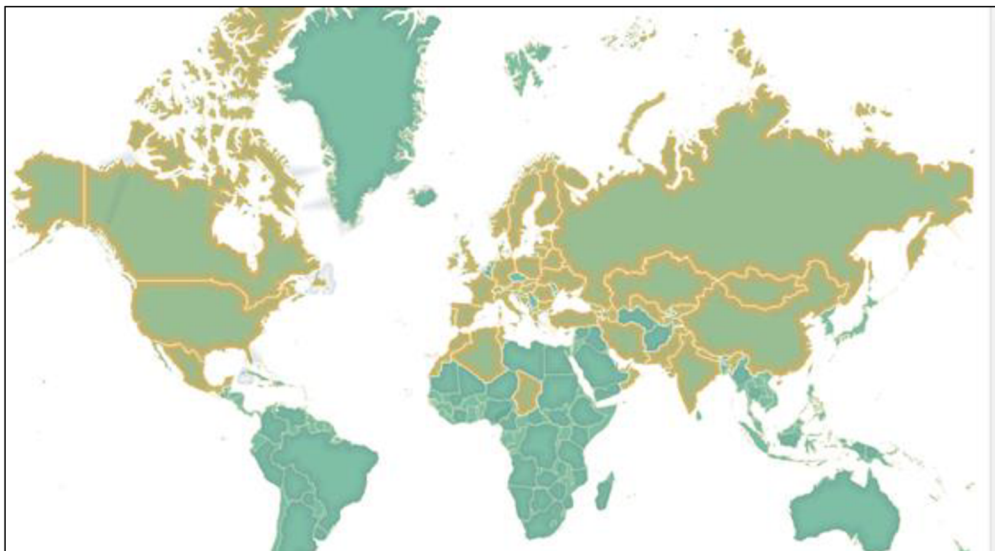


Figure 12: Combined species distribution layers output in ArcGIS Pro

For the final stage of visualisation and design, the map scale was set to 1:150,000,000 in ArcGIS Pro, and the species distribution maps were exported in PNG format. Once added to the profile, additional features were added to the map directly in Canva to provide more information and enhance the visual appearance. Continent labels were added on top of the image using 'Nanum Pen Script', which is the font used on the species profiles. It has a hand-written appearance which gives the impression of being more casual and inviting. A map title, legend, scale and description were created to provide more context and information to the map and what it was showing. A final addition was graphics of the species to both make the map more appealing and cement the idea that the map is showing the presence of that species (figure 13).



Figure 13: Final Global Species Distribution Map – species profile

5.3 Web maps

Two variations of interactive web maps were created for this project; a series of maps created for the StoryMap using ArcGIS Pro and ArcGIS Online, and maps directly embedded into the educational platform created using a combination of GeoJSON data and layers created directly in Mapbox. The processes involving the development and creation of these web maps are described in the following chapter.

5.3.1 ArcGIS Online

The maps created in ArcGIS have been outlined in chapter 4.4. A series of maps were created showing species observations within Glenveagh National Park as well as additional thematic content e.g., land cover type and geology. Further basic maps were developed to show landmarks and physical features in Glenveagh. Each of the map layers designed and produced in chapter 4.4 were uploaded as individual web layers to ArcGIS Online. The web layers were uploaded as feature layer types to enable editing if needed. Following this, the online map viewer in ArcGIS Online was used to build several maps using the uploaded web layers for the StoryMap presentation. Some of the layers were further formatted in ArcGIS Online as some of the design features in ArcGIS Pro were unable to be viewed online. Pop-ups were created for the species and landmark maps to increase the interactivity for the user.

Three maps were included in the StoryMap presentation:

- 1) Glenveagh features and landmarks
- 2) Glenveagh land cover and geology
- 3) Glenveagh species distribution

5.3.2 Mapbox

In the planning and designing stage of the educational web platform, interactive maps embedded straight into the website were identified as an essential geovisualization tool to use for this project. Mapbox was the chosen platform to create these maps, with further edits conducted using Visual Studio Code software. Three maps were planned to be included on the website, utilising existing data processed and analysed in ArcGIS Pro which was exported in a GeoJSON format and new data sets created using both Mapbox studio and GeoJSON.io. The three maps utilised were:

- 1) Home Page – Map of Glenveagh (where to find us map)
- 2) About Page – Glenveagh features and landmarks
- 3) Flora and Fauna Page – Species of Glenveagh

To create a sense of consistency on the web platform, the same designed map style created in Mapbox was used as a background to all maps. The background topological features were formatted to show variations of light green. Land features were all set to RGB 235, 240, 235 while water features were set to a slightly darker tone (RGB 195, 215,190) and labels RGB 130, 170, 130. A hillshade layer was also enabled on the map background to provide texture to the maps and further elevation information.

The Glenveagh park boundaries and the landcover data showing only the water features were uploaded into Mapbox and added to the map style to create a basic blank map of the park to use as a reference point to find its location on the map. The customised symbology created for this research project (chapter 5.1) was uploaded into Mapbox in SVG format. GeoJSON.io was utilised for the two remaining maps to create new datasets to be used in the interactive maps. MapCarta was used to identify a range of features within Glenveagh National Park e.g. lakes, mountains, and castles which were subsequently plotted onto the map in GeoJSON.io. This web application was similarly used to create a new species dataset with one point representing each species as opposed to several hundred observation points. The species observations SHP in ArcGIS Pro were referred to so the selected marker location for each species was in the correct location or habitat type (figure 14).

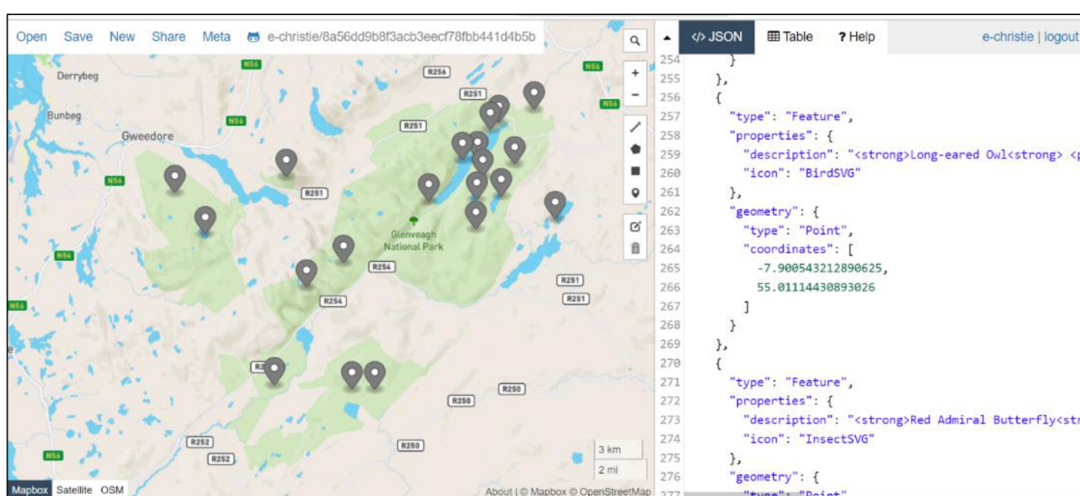


Figure 14: GeoJSON.io Glenveagh feature points creation

Visual Code Studio was used to combine all map components into one HTML file to be embedded directly into the educational web platform. A HTML document was created, and the map style from Mapbox was added containing the background and Glenveagh boundary data. The map position was set to the coordinates of the National Park so that the map would reset to that location every time, with the zoom level set to 10.

Code was additionally implemented to create pop-ups for each species and landmark feature to provide the user with further information. The font colour was set to match the shade of font used on the main text on the website (RGB 100, 105, 110). As the icons were already uploaded into the Mapbox style, they were able to be called and implemented directly instead of adding images into the HTML document. The end-product of the interactive Glenveagh Features map is shown in figure 15, whereas the HTML code can be viewed in the attachments.

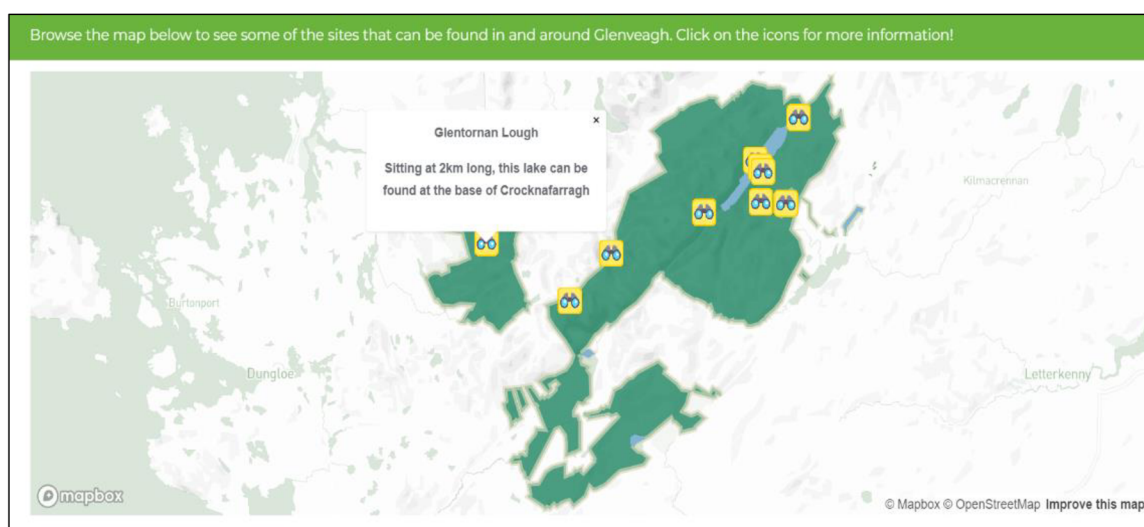


Figure 15: Web map showing geographical features and landmarks

5.4 Educational Resources and Activities

The learning materials and resources developed were a focal point of this research. The aim was to communicate complex geospatial and biodiversity data in a simple and visually pleasing manner which could be understood and retained by the general public. Many visual variables and principles of geovisualization are considered and utilized. This sub-chapter is further divided into three sections representing the three categories of learning resources produced: 1) children's activities, 2) species profiles for each of the sample species 3) a StoryMap presentation on Glenveagh National Park and conservation. The key design consideration is the intended audience of each component. Visualizations need to be adjusted according to the user's skill level, age and interaction time. The decision-making process, design and creation of these resources and activities are described below.

5.4.1 Children's Activities

Although other aspects of the educational platform were intended for wider age groups when it comes to educational activities the age range must be more specific as school-age children learn more advanced information every progressive year of their education. The children's activities were designed for an approximate range of eight to ten-year-old children. It was crucial to gauge what kind of skill level children in this age range should have to ensure that the activities were both fun and educationally beneficial. The Irish school curriculum is available online. Using the national geography curriculum for third and fourth classes (8-11 years old), activities were designed based on the concepts school children learn from the curriculum. Children at this age should be starting to make simple maps of their environments as well as learning about basic map features. Knowledge of local flora and fauna and what affects their lives in the environment is also a learning objective for pupils. Excerpts of the curriculum are shown in figure 16.

The local natural environment

The child should be enabled to

- investigate and become familiar with some natural features in the local environment
aspects such as
names, locations relative to other features
shape and appearance, flora and fauna
of features such as
stream, river, hill, valley, mountain,
lowland, beach, bay, headland
- estimate distances and establish cardinal directions during the exploration of these features
- observe and explore ways in which these features have affected the lives of plants, animals and humans
influence of hill, bog or stream on transport, roads and bridges, towns and cities
the stream, mountain, beach etc. as a habitat for plants and animals
- investigate the ways in which these features have been used by humans and the changes which have occurred as a result
beach and bay used for leisure and recreation
supply, treatment and distribution of water from rivers and lakes to homes in the area.

Linkage
People living and working in the local area—Natural environmental features and people

Integration
Science: Living things; Materials

Figure 16: Irish national school curriculum for geography ages 8-10

20 children’s activities were created in total; one attached to each of the species’ profiles. In addition to this, a species checklist and a map guide teaching basic map elements and principles were also created. A complete list is provided in table 11. The activities varied between geography and biology-related tasks. To maintain consistency in the resources, the font, colour scheme and layout were all kept constant. The background of the document is set to an off-white colour (hex #ffff5) with the two other colour scheme colours being dark green (hex #01642c) and two tones of brown (#582308, #c8a47b). These colours were selected for their earthy and natural tones tied into the environmental theme. Two fonts were chosen: one for the document title (‘Chewy’) and the other for the remaining text (‘Nanum Pen Script’). These fonts were chosen as clear but ‘more fun’ fonts which may appeal to children more as they look less formal than traditional fonts.

Table 11: Complete list of created children’s activities

Activities List	
Create your own symbols	Glenveagh Bingo
Wildlife scramble	Lake mapping
Missing map features	Name the country x 2
Make your own species profile	Colour by number
Ireland Wildlife Map	Pollinator maze
Match the baby name to the animal	Info sheet- Freshwater habitats
Bird Migration and ID	Wading bird checklist
Build your own garden bird map	Animal Identification
Butterfly checklist	Draw the deer map
Draw your own map	Map guide and checklist

A map guide was designed to introduce the user to the concept of maps and their various elements. The goal was to create a document showing various map features and inform the user 'how to understand map content', which could be used for reference when carrying out map-related activities. As the school curriculum specified that students for the intended age bracket should be learning about their local and national maps and geography, a map of Ireland was used for this activity. The map features that the student will be taught about are the map title, symbology, labels, legend, compass and credits. Simple definitions for each concept were provided to further enforce their purpose. Simple but visual symbology was used to represent several phenomena on the map. Where possible, symbology that directly related to the phenomena was chosen to simplify the map e.g. castle feature uses a castle symbol etc. The same document font was used in the map labels for consistency as it is both clear and easy to read. The font colour was black for the city labels and blue for the sea labels to create an association with the water. Although not an essential addition to a map, a compass was added to teach about the different directions and as a fun additional graphic. The full created document is shown in figure 17.

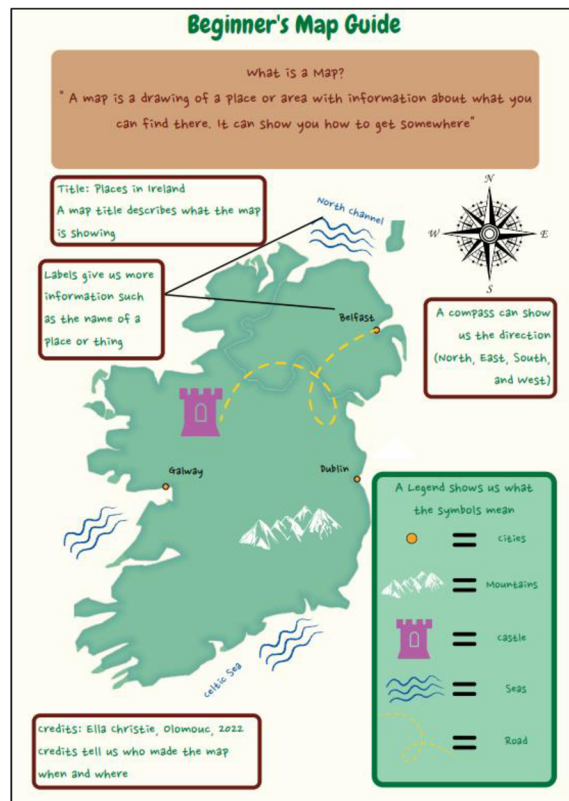


Figure 17 – Final children’s map guide – educational resource


Various map-making activities were planned and created for this project to teach the concept of spatial thinking and meet the learning objectives of the school curriculum for geography. The curriculum stated that school children in this age group should be taught spatial awareness by mapping their surroundings and local areas (NCAA, 2015). The garden bird map activity is designed to meet this goal by encouraging the user to design a map of their garden or a local greenspace and document the birds that visit there. The document provides a blank map frame for the user to be able to draw their space, nevertheless, areas of the document are sectioned and labelled to remind the users to include basic map features e.g. a title or legend. A brief description of the activity and examples of what the participant can include are also provided.

As previously stated in the introduction of this document, environmental education is best enforced outdoors in a natural setting (Kamarainen et al., 2013; Chang, Chen and Hsu, 2011). Taking this into consideration, an activity was designed specifically for children visiting Glenveagh National Park. This map activity encourages the user to create a map of their choosing while visiting the park, using an outline of Glenveagh as a frame. Similarly to the previous activity, the map border was sectioned and labelled to ensure the user included map features such as a legend, credits and title. As the user can map any phenomena they wish, examples were provided of potential symbology that could be used in their map. This activity enables the user to use their creativity and map phenomena that they are interested in while also encouraging them to use their spatial awareness skills to map accurately using the boundary of Glenveagh. Some of the Loughs were included on the map for the user to have reference points. The completed activity can be seen on the next page in figure 18.

Activity Time: Create Your Own Map

use the outline below to fill in your own map. You could plot your walking route, animals you have seen, or interesting places you visit. Don't forget your map titles and legend

Title: _____



Made By: _____
 Where: _____
 Date: _____

Legend Example:

—	=	walking route
🐾	=	Animal
✖	=	interesting place

My Map Legend:

Figure 18 – Design your own map of Glenveagh - children’s activity

Biodiversity is a core component of environmental education, some of the created activities aimed to educate users on various biological concepts such as migration or lifecycles, which are mentioned in the biology national school curriculum for ages 8-10 years old. Migration is one of the great wonders in the animal kingdom. It is also an ideal learning concept for this project as it incorporates both biological and spatial concepts. A children's activity was created in two parts; the first was a bird migration information sheet, and the second was a migrating bird identification activity. The same world map used for the species distribution maps was utilised for this activity with graphics overlaying it to visualise the act of bird migration. Basic facts and concepts about bird migration were given in text boxes surrounding the map, teaching the users what is currently known about why birds migrate. As this activity was relatively information-heavy, an interactive activity was included to boost engagement and participation from the user. An 'identify the migrating bird' activity was created using images obtained from Unsplash. Figure 19 displays the end-product of this children's activity.

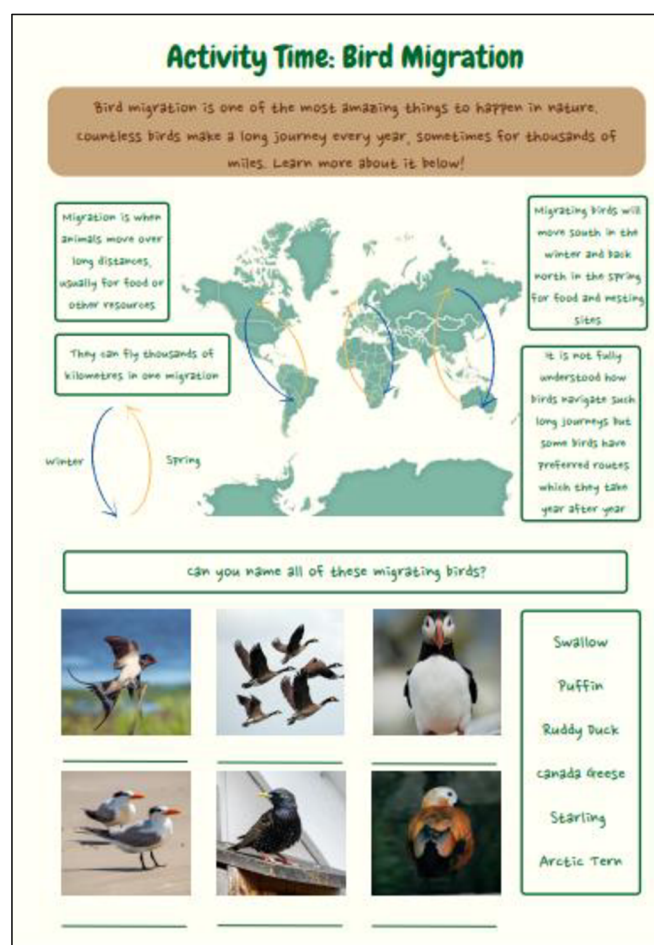


Figure 19- Bird migration information sheet - children's activity

Another activity that was designed specifically to engage the user at Glenveagh National Park was a species checklist. A full list of all of the study species for the user to find and cross off as they spotted them. This activity encourages the user to visit the park and utilise identification skills to locate species. High-resolution images were provided with the species names to provide a photo-realistic representation of each species to make it easier for the user to identify. Although graphics can provide a good visual depiction of a species, they can sometimes alter biological accuracy due to artistic interpretation.

5.4.2 Species Profiles

An individual species profile was designed and created for each of the 20 study species. The species profiles aimed to provide a detailed analysis of each species, including information about their physical description, conservation status, habitat preferences, diet and a map of the species' global distribution. In terms of design, the species profiles and children's activities utilised the same basic format to keep consistency between the downloadable resources (see section 5.4.1 for specification). Each profile was kept to the same design and layout template. The creation of this template and the information is described below for one of the study species.

The red deer is one of Ireland's most iconic and easily recognisable mammals. Three components were used to build the profile: existing literature, biodiversity analysis and visualisation. Background research was conducted for each species, both on their physical characteristics and conservation status, globally and in Ireland. Habitat analysis was carried out using the open-source data obtained for this project as described in the chapter. A high-resolution image of each species was provided for reference. Furthermore, graphic depictions of each species were also incorporated to enhance the visual appearance of the document. Graphics were also used for the species description section to directly link physical characteristics to the information that was being provided. The habitat and diet preferences section also utilised graphics to enforce concepts and descriptions of information. Creating a visual link with textual information aids in enforcing what is being communicated to the user, particularly if they are at a young age. The finalised document is pictured in figure 20.

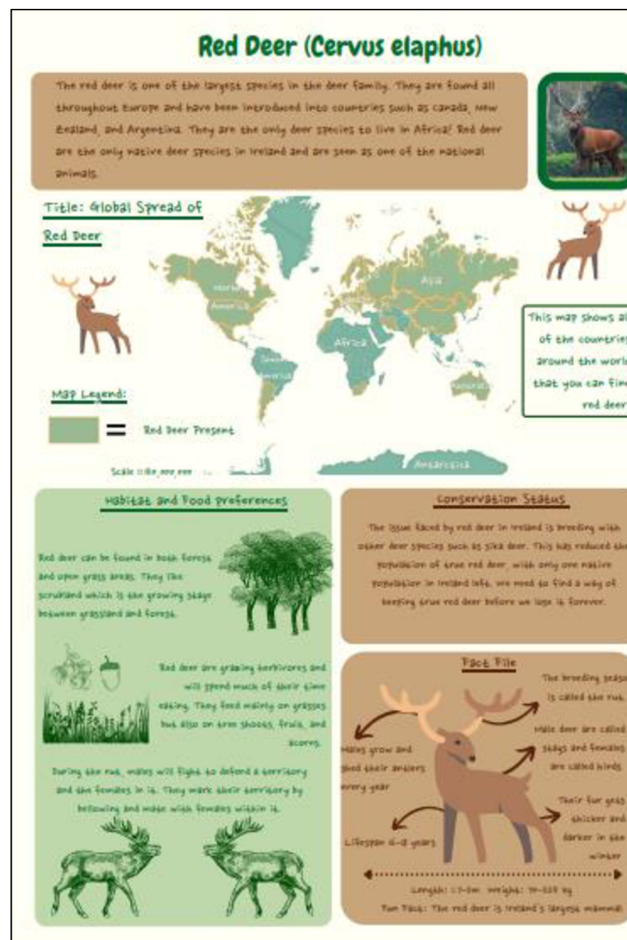


Figure 20 – Species profile for the red deer – educational resource

5.4.3 StoryMap

Although the educational resources were designed for young school-aged children, it was determined that since the educational web platform itself was designed for all potential park visitors, a resource needed to be created for an older demographic as well. As a result of this, Esri's StoryMap web application was used to create an interactive presentation for potential park visitors to educate them further on the history of Glenveagh National Park, a more detailed input of the habitats and species within the park and finally the importance of conservation and the preservation of National Parks (figure 21). The goal of this resource was to utilize interactive maps to navigate through several sections of more complex spatial and biodiversity information.

The key concept of this presentation was interactivity, to allow the user to interact with maps and media to learn more detailed history and environmental background of Glenveagh National Park. A series of maps are used in this presentation to communicate spatial information with the user. Esri's StoryMap application has a series of preset themes which can be used to set a design for your presentation. Nevertheless, a new theme was created using the same colour scheme used on the educational web platform, white background with green headings (#6AB43E) and a grey/blue text (#64686D) with orange buttons (#F6BA56). The maps used in this presentation were similar or the same as the interactive maps embedded onto the web platform, showing species distribution in the park, tourist landmarks and features and landcover. These maps will enable the user to turn on and off layers, click on features for pop-ups of more information and zoom in and out to explore different areas.

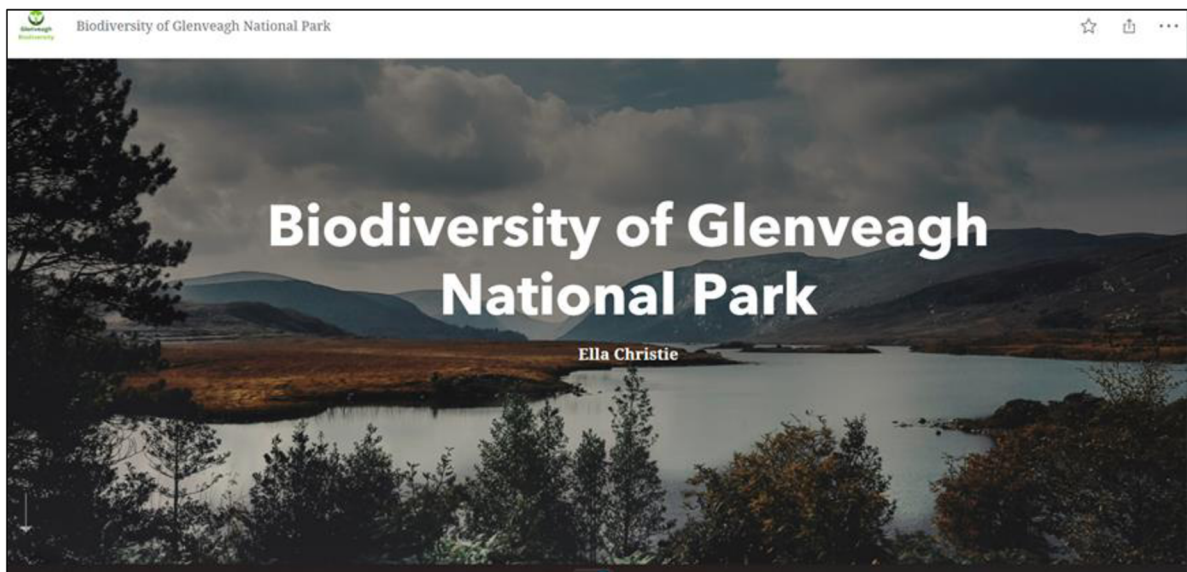


Figure 21 – Cover page Glenveagh National Park StoryMap

5.5 Web platform

This sub-section outlines the process of developing the educational web platform to host the maps, learning resources and materials for this research project. The platform is the pivotal component of this research. This section has been sub-divided into three further sections to detail the processes and decision making in terms of the layout and structure, design and content of the educational platform.

5.5.1 Layout and Structure

Before the creation of this web platform, plans were laid out considering the user to hypothesise an ideal layout and structure for the intended audience. The developed concept was to create a platform that would be easy to navigate, simple and clear. The users for this project would likely not have much biological or geospatial background, therefore, it was imperative to make this platform simple and concise. It was decided that the platform would be divided into four pages: Home, about, flora and fauna and contact. The home page would enable the user to reach all of the most important web features and information using buttons and links. The aim of this is that the home page is the first page that the user will interact with, therefore, it should be dynamic and create as much accessibility to the rest of the platform as possible. The website menu was structured to create a natural flow of information. Firstly, the home page, contains key information and links, the about page provides more information about Glenveagh and the platform, and the flora and fauna section contains all learning resources. Finally, a contact page for users to be able to get in touch with any questions or queries.

As visualization is a key concept in this research, the user is the defining factor when contemplating a design for the web platform. The aim was to keep the website simple while incorporating colours and themes that reminded the user of the environment or nature. The colour scheme incorporated just four colours: green (#6AB43E), white (#FFFFFF), blue/grey (#64686D) and orange (#F6BA56) which were used consistently throughout the website. The layout alternated between white background with green headings and grey/blue text or green background with white text. All buttons used on the web platform were orange. A header and footer were included on each page to provide contact information and inform which page the user is currently visiting. The Elementor plugin was utilised in building the website to help create a consistent structure and layout. Using this plugin the user can create a new section to add features or content and choose from several features to add to the webpage e.g. images, HTML code, headings and text (figure 22).

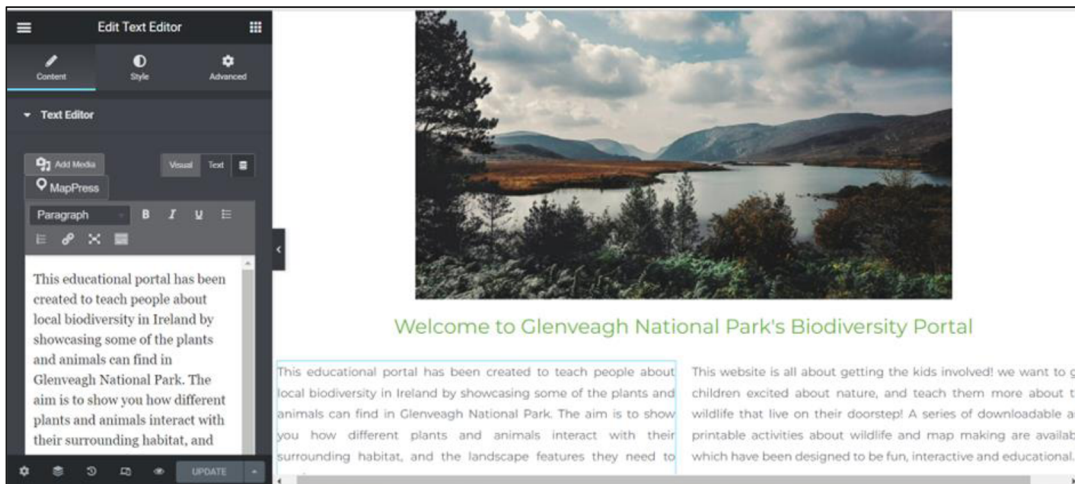


Figure 22: Using Elementor to add and edit text on the website – website creation

5.5.2 Logo

Logos can be useful advertising tools as they represent a whole company or organisation with one image. A logo was created for the created web platform to create something recognisable which would stick in the mind of users. Canva was used to create a personalised logo which matched the platform's colour scheme. The logo was intended to be used on every webpage of the website, as well as the StoryMap presentation to advertise the portal's brand to users. Two variations of the logo were created: one light for a white background and one for a dark background. The main logo is pictured in figure 23. When embedded into the website, the backgrounds were removed to display solely the logo and name.



Figure 23: Glenveagh Biodiversity logo (main)

5.5.3 Features/Content

Interactivity and ease of navigation were focal in the planning of the website. The website needed to be engaging and exciting to hold users' interest and encourage them to retain spatial and biological information. Two approaches were taken to achieve this: through website features such as buttons, images and animations and the website content itself in terms of information provided.

Many website features were utilised to enhance both visualization and usability. Buttons were incorporated into each web page to provide shortcuts to specific information or reduce user input. Any button diverting the user to an external resource, such as the species profiles, were formatted to open them in a new tab so that the user could easily exit the document and still have their place on the website. A series of high-resolution images were included on the platform of Glenveagh and its various biodiversity. These images not only provide more visual context to the area of Glenveagh, and the species being discussed, but they also aim to engage the user and generate interest in both the topic and the park (figure 24). On the home page, animations were incorporated to show conservation statistics. The animation attracts attention to important information being communicated to the user (figure 25). Interactive maps were embedded into three of the web pages on the website to boost interactivity and create an element that users can engage with directly. They can explore spatial and biodiversity data themselves, being engaged through scrolling, zooming in and out and clicking on pop-ups. The website content was designed to generate interest in conservation and the National Park itself, to encourage users to visit and advocate for their local flora and fauna. The content itself was written in a friendly and uncomplicated manner to be comprehensible to users of varying backgrounds and biological and geospatial knowledge.

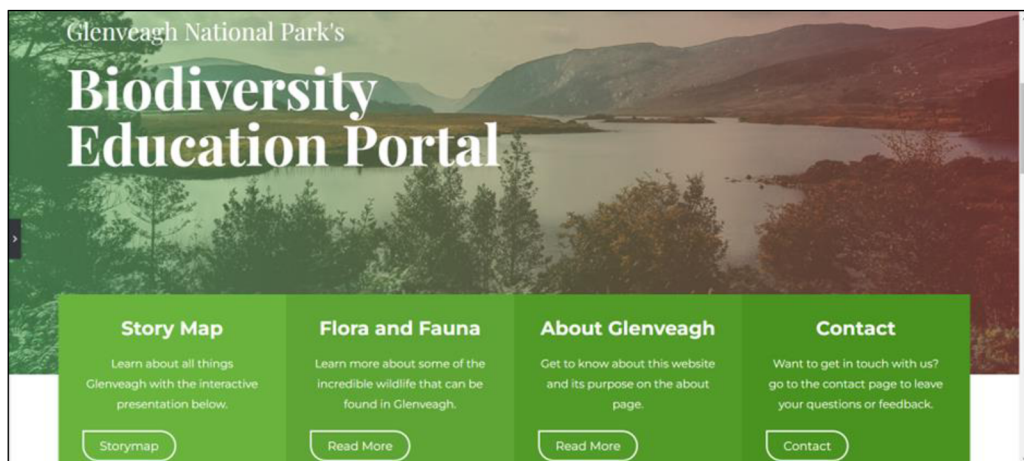


Figure 24 – Website homepage



Figure 25 – Animations of conservation statistics - website homepage

6 USER TESTING

The following chapter depicts the processes involved in the user testing component of this investigation. User testing was conducted using an online survey to evaluate the usability of the educational platform and its design. This section is divided into the survey content and design. The survey was shared with several individuals, namely those who worked in education and/or had families with children and resided in or had ties to Ireland

6.1 Survey Questions

In the initial stages of compiling a list of questions for the survey, there were two considerations. The first was that the questions must cover all the necessary topics e.g. design aspects, interactivity and created resources. Secondly, the survey questions needed to be designed with the user in mind. Hence, the list of questions should not be too long nor the questions too arduous to answer, and when possible, the questions should be phrased in a manner that enables short or predefined responses e.g. on a scale of one to five. Another consideration was to make the survey anonymous to reduce the risk of bias when answering questions. Anonymity can encourage participants to answer questions and provide feedback honestly. Despite this, gaining a broad understanding of the user's background and experience with geoinformatics was deemed important to determine their rough level of competency.

With numerous geovisualized elements to be evaluated, it was established that similar broad questions should be asked for the various end-products with categories that could be ranked by the user. The products to be evaluated were divided into the educational web platform itself, the interactive maps, species profiles, StoryMap presentation and the children's activities/resources. Implementing a rank-based system enable quantifiable and calculable responses e.g. using a scale of 1-5 the total user's responses can be averaged for an overall score. To gain a broad understanding of what the users favoured more/less about each product, the question was formatted to request the user to rank each product based on three components: layout and structure, content and design. When considering how the interactive maps should be evaluated, features such as navigation, interactivity and appearance were deemed more appropriate to rank. To supplement this with additional input on the user's ability to use the platform to locate and retain information, posing questions requesting the users to perform certain tasks using the website and resources is paramount. Although formatting most questions to have short, optional or ranked answers enables a more uniform and simply complete the survey, more detailed input is needed in terms of feedback. Providing an option for users to be able to provide detail on what they liked and didn't like specifically, errors or improvements that need to be made, or general feedback is a crucial component of user testing. It is this detail which enables a more critical evaluation of the end product. A compiled list of the finalised questions is listed in table 12.

Table 12: User testing survey questions

User Evaluation Survey Questions
1. What is your profession?
2. Do you have any knowledge of geoinformatics and/or geovisualization?
3. How would you rate the overall appearance of the website? Rank: (Layout and structure, content, design)
4. How would you rate the interactive maps in terms of: (navigation, appearance, pop-ups, clear what maps were showing)
5. Can you provide the name of the waterfall found in Glenveagh National Park? (Hint: using the interactive map on 'About' page)
6. How would you rate the species profiles according to their: (structure and layout, appearance, information and content)
7. How many species of amphibian can you find in Ireland? (hint: common frog species profile)
8. How would you rate the StoryMap in terms of: (Navigation and interactivity, appearance and layout, content)
9. When was Glenveagh National Park opened to the public? (hint: see StoryMap)
10. How would you rate the children's resources and activities based on their: (structure and layout, appearance, content)
11. What age range do you think that the children's activities are aimed at?
12. Would you recommend this website for families, school groups, or potential visitors to Glenveagh?
13. Do you have any comments or feedback for the website? (difficulties navigating or finding information etc.)

6.2 Survey Design

Esri's Survey123 software was the chosen product to create and design the user testing survey as it offers a drag and drops survey building process and design options, and it can be shared with and completed by users who do not have an Esri account. The green survey background colour and headings were selected from the theme options in the Appearance section to coordinate with the web platform's colour scheme. A brief introduction on the purpose of the survey was written to provide context to the participant alongside a link to the platform which they could use to refer to while undertaking the survey). All questions except the final question asking for more detailed feedback were set as 'required questions'.

Each question was reviewed to determine the best answer format to provide it. The types of formats utilised in the survey are single-line text, multi-line text, dropdown, single choice and single choice grid. Single line text enables personalised input from the user but limits the quantity of information they can input. This answer format is typically used for questions that only require a few words to adequately respond. In this use case, single-line text was required for the user to name a feature within the National Park. Single choice question formats provide a set of pre-determined answers for the user to select one from. They are best suited to questions with a short, definitive answer e.g. yes or no, A, B or C. Dropdown boxes were utilised to provide a list of categories for the user to select from concerning their profession and background in geoinformatics. The single choice grid answer format was used to create the ranking response questions. Each question in this format asked the user to rank the feature or component on a scale from very dissatisfied to very satisfied. The end-product as seen by the user is pictured in figure 26.

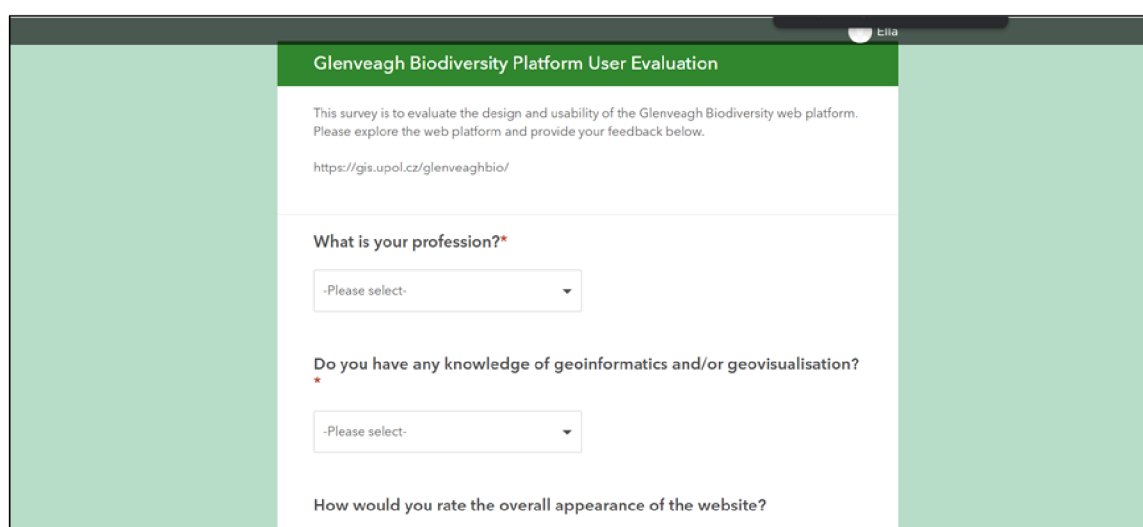
The image shows a web browser window displaying a survey titled "Glenveagh Biodiversity Platform User Evaluation". The survey text reads: "This survey is to evaluate the design and usability of the Glenveagh Biodiversity web platform. Please explore the web platform and provide your feedback below." Below this is the URL "https://gis.upol.cz/glenveaghbio/". The first question is "What is your profession?*" with a dropdown menu showing "-Please select-". The second question is "Do you have any knowledge of geoinformatics and/or geovisualisation?" with a dropdown menu also showing "-Please select-". The third question is "How would you rate the overall appearance of the website?". The browser's address bar shows "Lila".

Figure 26: Final survey design output – user view

6.3 Survey Response

The online user survey was sent to a number of participants (~35 people) of which there was 20 respondents total. This section will break down the results of the survey by question and evaluate the responses. The demographic of the participants were highly varied in terms of background and experience. 25% of the participants come from the education sector e.g. teachers, with a further 20% being students. Notably, two of the participating students were in teacher training programs. 35% of the participants did not feel that they met the criteria for any of the provided options, and therefore selected 'other'. In terms of awareness of geoinformatics and associated concepts, 50% of the participants had no previous knowledge of the subject. A further 25% of participants ranked their knowledge as basic. The majority of participants having limited knowledge in this subject was ideal as the educational platform was designed with the average potential park visitor in mind.

Web platform Evaluation

The participants were asked to rank the web platform on three criteria: layout and structure, content and design. Users gave an overwhelmingly positive response to the platform in terms of layout and structure and content with only satisfied and very satisfied responses provided. The information and content provided on the platform were particularly well-rated with 95% of the participants very satisfied. The overall design of the website similarly received mostly positive feedback with 90% of participants satisfied or very satisfied with the outcome. Nevertheless, 5% of the users were dissatisfied with the design and a further 5% had neutral thoughts on the appearance (figure 27).

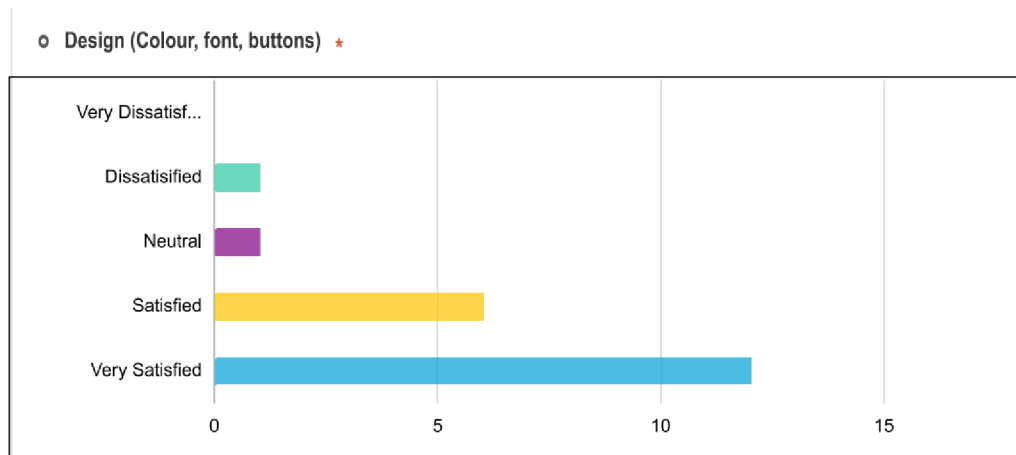


Figure 27: Bar chart showing satisfaction level of the website design - survey

Interactive Web Maps

Interactivity through web maps is a core geovisualization technique. The user's ability to navigate through spatial information and comprehend the information being shown to them is paramount. Users were requested to rank the interactive maps on a scale of very dissatisfied to satisfied according to the ability to navigate, appearance, map pop-ups and clarity on what was being shown. 60% of participants were predominantly very satisfied with the navigation capabilities on the maps, with the remaining users rating it as satisfied (25%) and neutral (15%) respectively (figure 28). Similar answers were provided for ranking the appearance on the map albeit slightly higher in satisfaction. The clickable popups received a 65% very satisfied response, although 5% of the participants were dissatisfied. 90% of the users were satisfied or very satisfied with their understanding of what the maps were showing them. Nevertheless, one participant (5%) was dissatisfied with how the map's purpose was communicated and the following 5% ranked neutral. Following this, the user was asked to use one of the interactive maps to locate the waterfall landmark in Glenveagh National Park and to provide its name. Due to this answer response requiring user input, there were some typing errors concerning the answer which was 'Astelleen Burn' waterfall. Taking this into account, 85% of answers contained the correct answer with misspelt responses included, demonstrating the participant's ability to navigate the map to locate information.

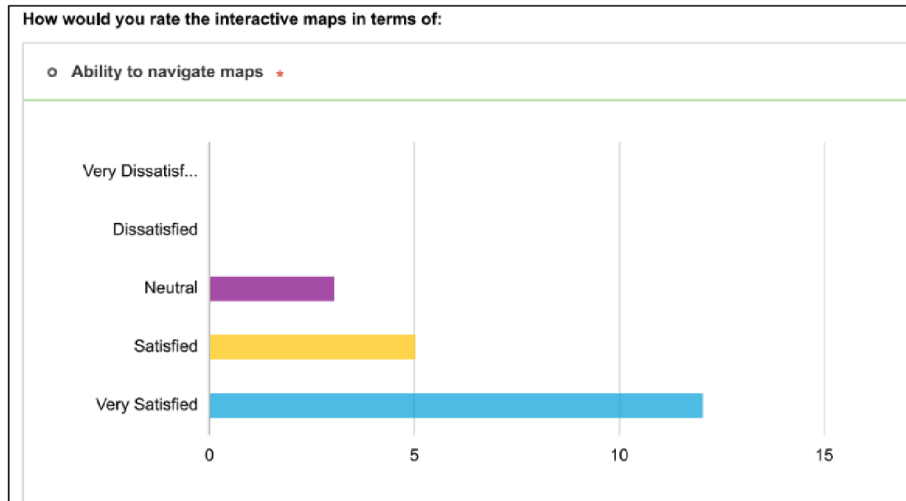


Figure 28: bar chart showing satisfaction rating of map navigation - survey

Species Profiles

A detailed profile was created for each of the 20 study species of Glenveagh containing information on habitat preferences, description and global distribution using static maps. The participants were requested to rate the profiles according to the structure and layout, appearance and information and content. 95% of participants stated that they were very satisfied or satisfied with the layout and structure of the profiles (70% and 25% respectively). The appearance and content of the profiles also received very high ratings with 100% of participants being satisfied or very satisfied (figure 29). 85% of participants were very satisfied with the information provided in the profiles. Participants were asked a question about amphibians in Ireland where the answer was given in a species profile for the common frog. 90% of participants were able to correctly answer this question.

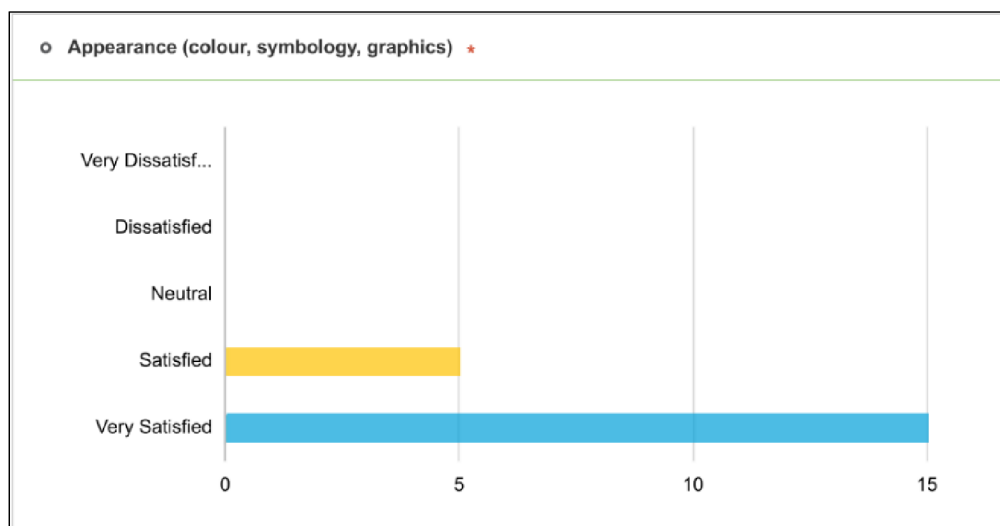


Figure 29: bar chart showing satisfaction ratings of the species profiles - survey

StoryMap

The StoryMap presentation provided a more detailed history and background to Glenveagh National Park, as well as discussed the importance of conservation using a series of interactive maps. The users were asked to rate the presentation on its navigation and interactivity, appearance and layout and content. Participant response to the StoryMap was highly positive. Very satisfied was the most common response to all three components with 70%, 75% and 70% respectively. 10% of participants had neutral feelings for the navigation and interaction of the presentation, with a further 15% rating the appearance and layout as neutral. To test the user's ability to locate and retain information provided to them, they were asked to provide the year Glenveagh National Park opened which was discussed in the presentation. 95% of the participants provided the correct answer to this question.

Children's Resources and Activities

Similarly to the other created products, the participants rated the children's activities designed for this project based on three components: structure and layout, appearance and content. The children's activities received the most positive user response collectively than any other product or feature. All elements were ranked as very satisfied or satisfied. Both structure and layout and content had ratios of 80:20 in terms of being very satisfied and satisfied, while the appearance had a ratio of 75:25. Participants were then asked to select from pre-defined responses which age group they thought the created activities were aimed at. 80% of the respondents stated the correct intended age group which was ages eight to ten. 5% of the participants believed that the activities were intended for ages 10-12, whilst 15% marked the option 'other' (figure 30).

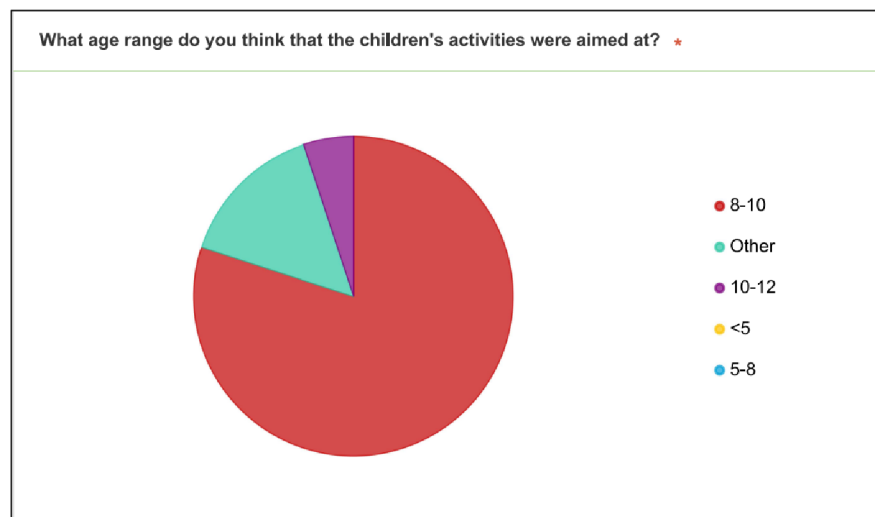


Figure 30: Pie chart showing user response to target age group of activities - survey

The final follow up questions in the survey were feedback based, asking if the user would recommend this platform to potential visitors to Glenveagh e.g. families, school groups etc. and to provide any comments or feedback. 95% of participants said that they would recommend the created platform with the remaining 5% being unsure. 13 of the 20 survey respondents provided comments, feedback and suggestions for improvement. Several of the participants stated that the platform was easy to navigate and find information. Another theme in the positive feedback was the appearance and design of the educational platform and the various elements and resources.

Users particularly enjoyed the use of graphics and colours. Participants found the content and information provided interesting and informative, one user stated they would revisit the site to read more while another said it was ‘nicely pitched to the target audience’. Constructive criticism and suggestions for improvement were also provided by participants. One issue some users had was locating the children’s activities which were on the second page of the species profiles. This meant some users spent time looking for the activities on the platform. One participant noted that having to click the zoom in and out buttons instead of being able to scroll inhibited the interactivity of the maps of the platform. Some smaller design specifications were noted by one participant with a suggestion for improvement including the main text font colour in the StoryMap, spacing in text boxes and the logo size. Loading times were also mentioned by a user as there were small delays in loading some of the larger file size species profiles. Overall the user evaluation and feedback were highly positive, participants responded favourably to the design and interactivity of the educational platform. The constructive feedback was also welcomed as an opportunity to make further improvements and adjustments. The complete set of user feedback and responses are listed in Appendix.

7 RESULTS

The following chapter summarizes the results of the thesis project. This includes the initial analysis, the created educational platform and resources and the results of the user testing. The produced results are the output of the thesis objectives and goals which were to analyse available biodiversity and thematic data and utilise geovisualization techniques to display this information on a web platform complete with educational resources. The intended outcome was to teach potential park visitors more about the biodiversity of local flora and fauna, taking into account geo-aspects of the landscape.

7.1 Analysis

The purpose of the analysis component of this investigation was to visualise complex biodiversity and spatial information to be communicated on a series of maps and educational resources. The analysis enabled a series of static and interactive web maps to be created as well as providing information which was written and discussed in the educational resources created. A total of 381 species observations were recorded in Glenveagh National Park, 179 of the recordings were of the white-tailed bumblebee which could be explained by the observations made at or within a close distance to beehives. Mammals and birds were the most highly recorded with 36 otter observations and 23 of the Eurasian bullfinch. The exception is the pygmy shrew which was recorded only three times, likely due to the difficulty in observing them.

Peat bog was both the most dominant land cover type and the habitat in which the most species observations and diversity were recorded. It is known for its low-quality nutrient soil. The mixed forest also made up a sizable proportion of the landscape and species present, as did water bodies. The main geology of the National Park is the main Donegal granite. The results of the habitat analysis and species distribution enabled further research to be conducted into the habitat characteristics of these identified habitats and why they are so crucial in the survival of so many local species. This data was simplified and condensed into the educational materials created for this diploma thesis project.

7.2 Web Platform and Resources

A well-structured, simple to navigate, interactive and highly visual website was created to host the information and resources created for this project. The website and its accompanying resources were the main output of this thesis project. 20 species profiles and 22 children's activities and learning resources, a Glenveagh National Park StoryMap presentation, six interactive maps and 20 static maps were created for this project. The educational web platform is described in chapter 5.5. utilised various website features to increase both its usability and visual appearances such as buttons, animations and images. Figure 31 displays the finalized output of the website's homepage. The series of interactive web maps were one of the key features of the web platform. They enabled the user to explore biodiversity and landmark data for Glenveagh National Park, able to click various features to obtain further information. Customized symbology was created for these maps to increase the quality of design and appearance of the maps (chapter 5.1). Pictured in figure 32 is an example of the completed Glenveagh species map with clickable pop-ups.

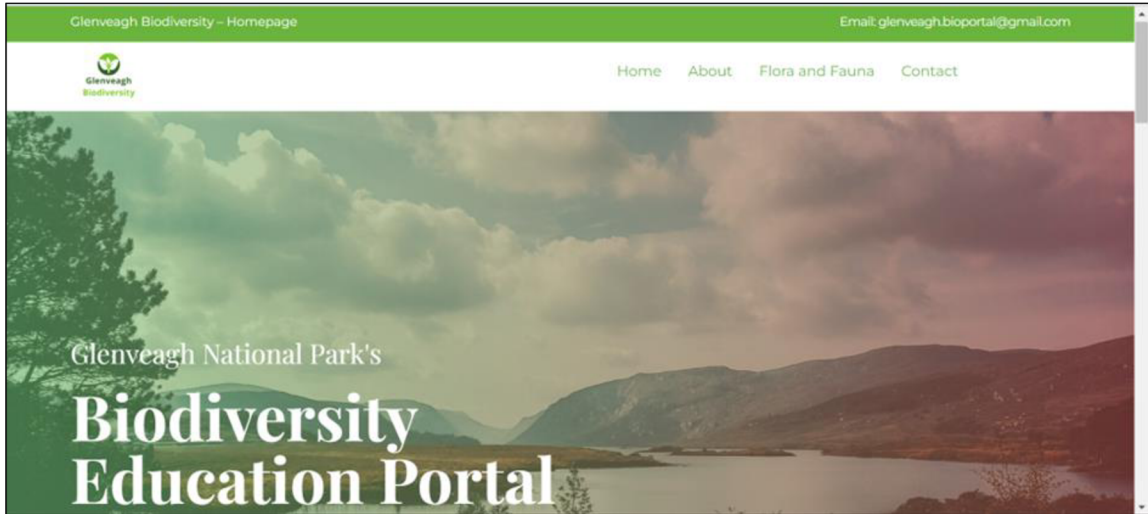


Figure 31 – Glenveagh Website Homepage

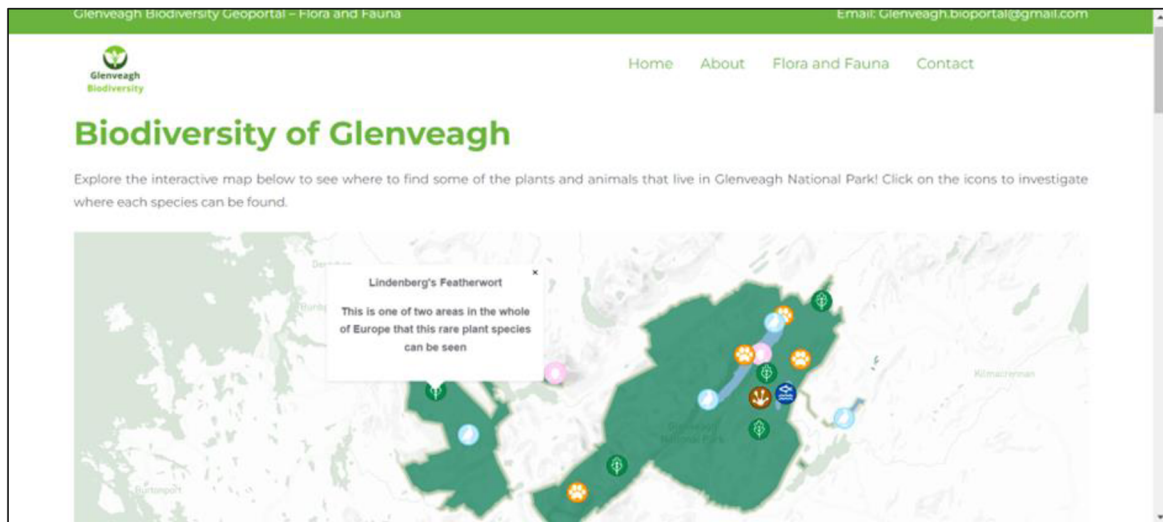
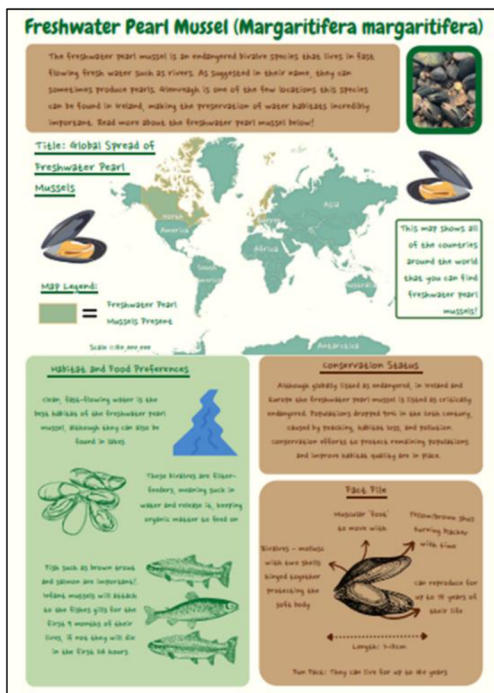


Figure 32 – Glenveagh Website Interactive Species Map with pop-ups

The species profiles were engaging and informative, using a uniform layout and colour scheme using natural colours to create an association with the environment. Each of the profiles contained a static map of the species' global distribution and utilised knowledge gained from the analysis stage to document habitat preferences and where each species could be located (chapter 5.4.2). The finalised output of a downloadable species profile is displayed in figure 33.

One of the key concepts of this thesis project was creating a range of educational resources to teach school-age children about their local biodiversity and associated geo-aspects. The children's activities were designed and created to a high visual standard, using Ireland's national school curriculum to determine the level of skill of the intended age group and what they should be learning about (chapter 5.5.1). The same colour scheme and fonts were used in the children's activities as in the species profiles to maintain a consistent design. Some of the data obtained and processed during the analysis stage of the project were utilised in the activities e.g. National Park boundary was used as a map frame for children to draw their map features. The output was a series of free, downloadable kids activities teaching the user about various biodiversity and biological processes as well as core mapping and spatial awareness skills. An example of the created children's resources is displayed in figure 34.



Figures 33 and 34: Created species profile and children's activity

The StoryMap presentation's target group was potential park visitors, designed to inform the viewer a more detailed insight into Glenveagh National Park and its history, ecosystems and biodiversity (chapter 5.4.3). The goal of this presentation was to use geovisualization methods through a series of interactive maps to communicate more detailed spatial and biodiversity information to the user. The output was a comprehensive background to Glenveagh National Park, which the user was able to scroll through with ease, interacting with the maps through clickable popups, switching on and off layers to show different information and zooming in and out on features (figure 35).

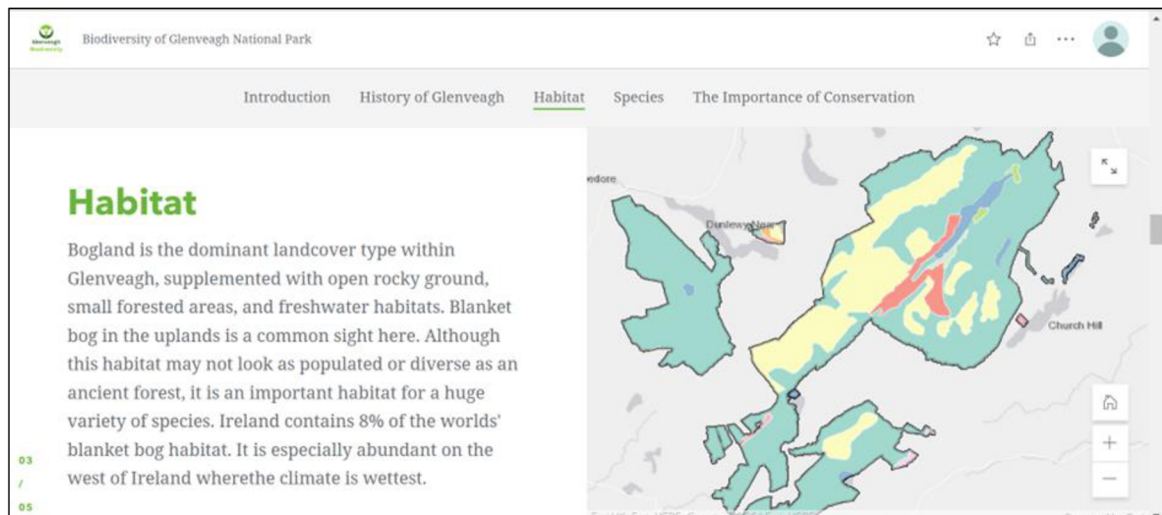


Figure 35: StoryMap - Habitat Page with Interactive Landcover Map

7.3 User Testing

The user testing resulted in 20 completed responses through an online survey created with Esri's Survey123 web application (see further details in chapter 6). The survey required the participants to navigate through the website and complete some basic tasks using the various website features and resources created. Following this, they were asked to rate the quality of the various created components and answer some questions to understand how easy they were able to locate and retain the information provided. The response was overwhelmingly positive, particularly in terms of design and appearance. The downloadable resources in particular proved very popular and were ranked very highly (100% satisfaction rate). Users were asked to provide some optional more detailed feedback on the platform and its associated resources. This was to gain a better understanding of what features worked well and where there was room for improvement. Some small formatting issues such as spacing between text and borders were highlighted which were corrected on the platform following the user survey. One note that was provided by two participants was the placing of the children's activities on the second page of the species profiles, making them slightly harder to locate. Some of the positive comments repeated by respondents were the ease of navigation and overall interactivity of the website which was a key goal in the planning and development of this platform. A complete list of user comments and feedback is provided in Appendix 1.1.

8 DISCUSSION

The purpose of this thesis research was to create geovisualized interpretations of analysed biodiversity and related environmental data to educate the target audience on local flora and fauna as well as their related interactions with their ecosystem. The produced output was a user-friendly, well-designed web platform containing a series of interactive maps, information and further educational resources. After this work, the various steps, procedures and outputs were reviewed critically to identify any limitations or room for improvement in the methods used or created outputs. This chapter will review and discuss these points and following this will provide suggestions for the future potential or direction of this research.

8.1 Critical Review of Procedures, Methods and Results

8.1.1 Data Limitations

As previously stated in chapter 4.2, all data utilised in this project was obtained from open data sources. Open-source data plays a vital role in scientific research and is a crucial resource. Nevertheless, there are sometimes limitations that arise when utilising data. For example, the CLC dataset specifications (listed in sub-chapter 4.2.2) state that the MMU is 25ha/100m. Although this is a good resolution, since Glenveagh National Park is a small area (approximately 170 km²) the accuracy may not be detailed enough to provide a comprehensive breakdown of land cover within the park. Furthermore, some studies have been conducted assessing the accuracy of the CLC dataset, stating that although on larger scales it functions well, it is less reliable on smaller scales (Ovejero Campos et al., 2019). The CLC dataset was used in this project to incorporate Copernicus data into the thesis. It is a vital data resource which can monitor land cover change over time, providing an insight to land cover properties across Europe.

Another consideration to be made is biodiversity monitoring data. The advantage of GBIF is that it is a multi-governmental collaborative approach to creating open-source species observation data globally. The observations logged on the platform are from accredited organisations and resources. Nevertheless, one could argue that there are slight biases shown in the correlated data, considerations need to be acknowledged and accepted. Firstly, some of the study species will have more recordings than others. This could be due to several factors including that some species are more heavily monitored than others, some are easier to observe and therefore recorded more often and some rarer protected recorded species may not have current data released online for their protection. These reasons can cause variations in the number of observations per species which can in turn affect the habitat analysis e.g. more observations means a more likely chance of habitat variations. Furthermore, what also needs to be considered is that species observations may be slightly biased since surveys are most likely to be conducted on paths and trails made for human use, therefore when analysing species data, observations are likely to be observed on the map nearer to these. Hard to access areas may have an abundance of wildlife but are far less likely to be surveyed. Nevertheless, with these considerations, observation data is still a reliable method of analysing and assessing biodiversity.

8.1.2 Analysis

The analysis component of the project aimed to identify patterns in species observations and various related phenomena e.g. land cover and geology. The information identified through the analytical stage was utilised in the species profiles, StoryMap and website to provide the user with accurate and detailed information about the habitat preferences of the study species. The analysis for this project was relatively basic, nonetheless, was sufficient to produce the desired outputs. Ecosystems are highly complex, as are the species which reside in them. Therefore, several factors can affect the presence or absence of species from a habitat. In the event of the continuation of this project, further thematic data would be analysed to help identify further contributing factors in the presence or absence of species in Glenveagh National Park e.g. temperature or precipitation. This could be used to create more complex visualizations and resources aimed for an older target audience.

8.1.3 Created Platform and Resources

The produced web platform and additional resources were created and designed with the target audience in mind; produced with high visual quality and interactivity while retaining an easily navigable simple structure. Creating the website, maps and various learning resources used a constant feedback loop to continually improve the quality of the end product. User testing identified some minor visual issues which were subsequently rectified.

8.1.4 User Testing

As previously discussed in chapter 6.3, the online survey was sent to several individuals who fell within the target audience for this web platform e.g. teachers and potential park visitors, particularly those with young children. 20 people partook in the survey to evaluate the created website and the additional learning resources. As with any form of feedback or user response, the more responses received the better. More responses can show patterns and trends in the kind of feedback being received. Furthermore, opinions are subjective and there may be elements of design choices that individuals do not like where several others do. A previously discussed issue in chapter 6.3 that the location of the children's activities was unclear was mentioned in feedback by more than one individual. This pattern was identified and using this feedback loop corrections were able to be made. The user surveying was conducted online due to geographical and time restraints. If repeating this project, if possible, user testing would be conducted in person to gauge user response to the platform. A school visit/s could be conducted to survey both teachers and their students. Glenveagh National Park has requested that any teaching materials relating to environmental education should be sent to them for use and to provide to teachers. This could offer an opportunity for further user evaluations in the future.

8.2 Suggestions for the Continuation of the Project

In a broad concept, this project took complex biodiversity and geospatial data and used geovisualization techniques to communicate this data to the average user through an interactive platform. This notion can be easily repeated for other National Parks, for example, the five other parks in Ireland which are all run under the same government. The creation of further platforms for other National Parks also creates a need for increased communication and data sharing. A method of managing this efficiently would be the implementation of an SDI based platform. This not only works for collaborative purposes but SDI could also be further utilised to streamline data and show further environmental and biodiversity data in real-time.

SDI was not utilised in this project due to not requiring automatically updated data. Continuing from this project, an SDI system could be implemented to automatically add biodiversity observations for species onto the website and interactive maps. This data could be used to evaluate temporal patterns of observations and species movements. As of late 2021, the Department of Housing, Local Government and Heritage within the Irish government announced that the six National Parks would be “reformed and rebranded” as a collaborative group (National Parks & Wildlife Service, 2022). The unification of these National Parks is a prime opportunity to utilise an SDI platform to share biodiversity and geospatial information.

Currently, discussions are being held with Glenveagh National Park’s education centre to provide the created outputs to both the centre and by request to local teachers and schools to aid in environmental education programs

9 CONCLUSION

This thesis aimed to analyse available data on the biodiversity of wild species and conduct a suitable geovisualization of the results using knowledge gained interpretation. This document has described and detailed the processes and procedures involved in achieving the aim and has demonstrated the successful completion of this project. The **analysis** has been fulfilled as described in chapter 4 and the **geovisualization** component is also demonstrated in chapter 5. The focus of this project was on the **educational potential of the analysed and geovisualized data for potential park visitors and school children**. Glenveagh National Park was chosen as a study area for this project due to its unique ecosystem and biodiversity. Open-source species observation data and related thematic data such as land cover were obtained and processed to show the distribution of a sample of 20 species found in the National Park and identify any trends in particular geo-aspects influencing their distribution. A series of static and interactive maps were subsequently created to show the habitat composition and species presence within Glenveagh as well as their global distribution.

The output of the habitat analysis was used to compile information on each species' environmental preferences which was included in learning resources to educate users on important landscape characteristics and provide insight on where they would be more likely to observe the species. The intended main result of the thesis project was a web page presenting the outcomes and **geovisualizations produced with an educational focus**. A website was created using WordPress containing a series of interactive maps, educational children's activities, species profiles and a StoryMap Presentation. The target age group for the children's activities was aged 8-10. Ireland's national school curriculum was referred to in the planning of the activities to ensure that an accurate level of geospatial and biodiversity concepts was being taught.

During the implementation of the diploma thesis, a need to conduct user testing was identified. This was to evaluate whether the goals of the thesis had been met by having users assess the interactivity, visualization and educational content of the end product. The results of the user evaluations demonstrated that users had a very positive opinion of the produced outputs, particularly the visualisation and design aspects. Nevertheless, there were some minor criticisms relating to formatting and the location of the children's activities which were rectified. Overall, the results of user testing supported that the diploma thesis aims had been met. **Environmental education** is an increasingly crucial method of gaining public support for conservation efforts. **Geovisualization** offers an engaging and interactive means of communicating **complex biodiversity** and geospatial information to a wide demographic of users.

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LIST OF ATTACHMENTS

Bound Attachments

Attachment 1: Table showing study species and data specifications

Attachment 2: Excel table showing presence of all species by landcover type

Attachment 3: User testing survey individual feedback comments

Free Attachments

Attachment 3 Diploma Thesis Poster

Attachment 4 SD Card x2

Attachment 3 Structure

- Thesis text – PDF
- Thesis poster – PDF
- Thesis website – Zip Folder (HTML)
- Thesis Data – 2x Projects (APRX)
- Web Map Source Code – Zip Folder (HTML)

Attachment 1

Species Name	Number of Observations	Dataset Citation
Eurasian Otter (<i>Lutra lutra</i>)	96,181	GBIF Occurrence Download https://doi.org/10.15468/dl.7b6tvs
Red-throated diver	33,052	GBIF Occurrence Download https://doi.org/10.15468/dl.rqjz43
Irish Mountain Hare	65,000	GBIF Occurrence Download https://doi.org/10.15468/dl.xdyjht
Freshwater Pearl Mussel	4,415) GBIF Occurrence Download https://doi.org/10.15468/dl.5q9n5k
Irish Stoat	876	GBIF Occurrence Download https://doi.org/10.15468/dl.7y5w6r
Golden Eagle	75,842	GBIF Occurrence Download https://doi.org/10.15468/dl.8r8kqa
Eurasian Pygmy Shrew	6,700	GBIF Occurrence Download https://doi.org/10.15468/dl.ngtnxf
White-tailed Bumblebee	67,057	GBIF Occurrence Download https://doi.org/10.15468/dl.z4xtsm
Bog Cotton	74,291	GBIF Occurrence Download https://doi.org/10.15468/dl.xuyj5h
Lindenberg's Featherwort	173	GBIF Occurrence Download https://doi.org/10.15468/dl.5m6dyf
Eurasian Bullfinch	255,718	GBIF Occurrence Download https://doi.org/10.15468/dl.cbvuuu
Devil's Bit	62,514	GBIF Occurrence Download https://doi.org/10.15468/dl.nzezc3
Red Admiral Butterfly	137,859	GBIF Occurrence Download https://doi.org/10.15468/dl.ce6w2j
Eurasian Curlew	105,674	GBIF Occurrence Download https://doi.org/10.15468/dl.ffuwes
Red Squirrel	454,192	GBIF Occurrence Download https://doi.org/10.15468/dl.rcd6uf
Red Deer	123,206	GBIF Occurrence Download https://doi.org/10.15468/dl.8grvhe
Common Frog	286,680	GBIF Occurrence Download https://doi.org/10.15468/dl.5agups
Heather	634,224	GBIF Occurrence Download https://doi.org/10.15468/dl.ec8xhq
Long-Eared Owl	298,149	GBIF Occurrence Download https://doi.org/10.15468/dl.3c3rdy
Birch	323,984	GBIF Occurrence Download https://doi.org/10.15468/dl.m76896

Attachment 2

Species	Landcover Type									
	Pastures	Land principally occupied by agriculture, with significant areas of natural vegetation	Broad-Leaved Forest	Mixed Forest	Coniferous Forest	Natural Grassland	Bare Rock	Sparsely Vegetated Areas	Peat Bogs	Water Bodies
Birch				X					X	
Bog Cotton									X	
Common Frog				X					X	X
Curlew	X								X	X
Devils Bit				X					X	X
Eurasian Bullfinch	X		X			X		X	X	X
Eurasian Otter			X	X		X			X	X
Eurasian Pygmy Shrew		X				X			X	
Freswater Pearl Mussel	X									X
Golden Eagle				X		X			X	
Heather								X	X	X
Irish Hare				X				X	X	X
Irish Stoat				X					X	X
Lindenberg's Featherwort							X	X	X	
Long-eared Owl	X					X			X	X
Red-throated Loon	X			X		X			X	X
Red admiral Butterfly				X					X	X
Red Deer				X		X		X	X	X
Red Squirrel			X		X	X			X	X
White tailed Bumblebee				X			X		X	X

Attachment 3 – Survey Response

Response	Count
Well presented website, the interactive map really highlights the variety of life in the park. The activities look really fun and the animal checklist would be a great scavenger hunt competition for kids.	1
Website was easy to navigate and I was able to find all the information I needed	1
Website looks good on mobile, is easy to navigate but could have improved load speeds as some pages took a while to appear (usually content heavy ones.)	1
Website is easy to navigate, graphics and content are interesting and not too 'wordy'.	1
Very easy to navigate, I particularly enjoyed the Story Map and how the content changed as you scrolled. I also thought the Species profiles were laid out really well, the graphics are really engaging!	1
The overall layout of the website was amazing. It is clear and easy to navigate, and provides a vast amount of useful information, both about Glenveagh itself, and the wildlife that is found there.	1
Main comment is use of green for text. Fine for headings but main body text might be better in black because of accessibility issues. Layout is good, I found it easy to see and understand most information. I am viewing on a phone so not ideal for maps but still able to zoom and read. Any boxes with text in them could have a bit of space between the box outline and the text. The logo is small in top left corner, could it be bigger without the text (so image/icon only) as it's repeated next to it anyway. Overall nice and clear. Very interesting to see, I would definitely revisit to read more. Great job.	1
It worked really well on mobile	1
It was very good, good work :)	1
It took me a while to find the children's activities section, wasn't obvious. Design is very aesthetically pleasing, better than most websites	1

I thought the website was well laid out and easy to navigate. The Story Map page did not have the 'Home, About, Flora and Fauna, Contact' links at the top of the page - adding these would make it easier to move on to the next section of the website. There was an abundance of interesting facts and figures given in the species profiles, and the information was nicely pitched to the target audience. I especially liked the 'fun facts' section at the end of each profile. The activities are structured in a way which will reinforce learning and I think the children will enjoy doing them all.	1
I thought the website maps were good, however not being able to use the scroller on the mouse to zoom in and out made it more difficult to navigate. The website colour scheme and overall layout were great. Would have liked childrens activities separate from species profiles as they took some time to locate	1
Clear layout, precise and concise information, and fun activities, it's a great website. No difficulties at all	1

Answered: 13 Skipped: 7