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Implementing and Developing an Interactive Atlas for the Global Naturalized Alien Flora (GloNAF) Database

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Implementing and Developing an Interactive Atlas for the Global Naturalized Alien Flora (GloNAF) Database

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Cartography M.Sc.

Master thesis

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Abstract

The Global Naturalized Alien Flora (GloNAF) project is a living database that represents the occurrence and identity of naturalized alien vascular plant taxa across the globe. This centralization of data can lead to insights into global bio-geographical patterns of invasive plants and can be used to determine drivers of relative richness of naturalized and invasive plant species on Earth. To encourage the accessibility of this dataset, an interactive atlas can allow researchers to filter, search, and visualize the data. Developing a framework to accomplish this task can be done by following a user-centered design philosophy.

Interactive atlases have been developing and changing rapidly the past three decades due to the rise of the internet and advancements in technology. Using D3, a client-side data visualization framework, the GloNAF dataset can be visualized to a high cartographic standard.

A five stage framework was developed that generates measurable success through communication with the target user group, iterative prototyping, and a competitive analysis. These methods prove useful in creating an atlas that applies user feedback to determine usability and utility features within an interactive atlas system.

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1   Introduction

The Global Naturalized Alien Flora, or GloNAF, project is a living database that represents the occurrence and identity of naturalized alien vascular plant taxa across the globe. As of October 2020, this large dataset consists of 13,939 taxa and covers 1,029 geographic regions (countries, states, provinces, districts, and islands) (Kleunen et al., 2019). Based of 210 different sources, the GloNAF database provides information on whether or not a taxon is naturalized, or has a self-sustaining population in the wild in a specific region. Non-naturalized taxa are marked as alien. The data sources include naturalized alien plant compendia, national and sub-national lists of naturalized alien plant species published in scientific journals, as books or on the internet, as well as compendia of national or sub-national floras with information on which species occur in the wild but are not native (Essl et al., 2019). The GloNAF database is an incredible resource for studying plant invasion and contains a wealth of data. While the database is still growing and being updated, this centralization of data has already led to insights into global bio-geographical patterns of invasive plants (Dawson et al., 2017). The GloNAF dataset has also been used in a study to determine drivers of relative richness of naturalized and invasive plant species on Earth (Essl et al., 2019).

To encourage the accessibility of this dataset, an interactive atlas can be created to allow researchers to filter, search, and interactively visualize the GloNAF dataset. This atlas can be used to further discover geographic patterns from regional to global scales. Studies and initiatives that utilize technologies for data integration, analysis, and communication have increased exponentially within the biological and ecological fields (Janicki et al., 2016). The development of web mapping and web Geographic Information Systems (GIS) technologies is a trend in geoinformatics (Farkas, 2017) and emerging technologies have greatly expanded the possibilities of online, interactive maps (Roth & Harrower, 2008). Web mapping applications offer an effective way to provide geospatial information without the need for additional software (Machwitz et al., 2019). Open source web mapping and data visualization JavaScript libraries, such as Leaflet (Agafonkin, 2010) and D3 (Bostock et al., 2011), combined with a user-centered design approach can lead to the successful creation of an interactive atlas for future biologists and GloNAF team members to view the GloNAF dataset.

1.1   Research Objectives

The overall objective of this research is to develop an interactive atlas for the GloNAF dataset that appropriately visualizes the dataset in regards to meeting the target users needs. Another objective is creating a reusable framework for interactive atlas creation that

utilizes the five-stage map application framework (Tsou & Curran, 2008) while achieving measurable interface success (Roth, Ross, & MacEachren, 2015). This framework can be created by leveraging core concepts from literature through a comprehensive background study and review. The third objective is to determine if any mapping functionalities are used in all types of atlases. If so, can a minimum standard of necessary functionalities be determined for interactive atlases?

2 Background

It is important to define what an atlas is, especially in this modern age of cartography. At its core, an atlas is a collection of maps. However, using this simple definition not only ignores equally important atlas functions but also overlooks the important coordinating role of the atlas as a storehouse for geographic information (Monmonier, 1981). To the layman, any book consisting mainly of maps is an atlas, but technically to the cartographer, no collection of maps deserves the name unless it is comprehensive in its field, arranged systematically, authoritatively edited, and presented in a unified format (Alonso, 1968). While compilation of an atlas might require the use of a collection of many large, spatially congruent data sets, an atlas is much more than that (Buckley, 2003). The Merriam-Webster definition does not provide any more clarity and arguably provides a dated definition that does not accurately define the word in the digital age of cartography: "a bound collection of maps often including illustrations, informative tables or textual matter" (*Atlas*, 2020). That earlier and general definition of the 18th century has reached its limits with the emergence of digital atlases and computer science and the modern definition has become more flexible regarding the organization, the spatial extent and the content of atlases (Panchaud et al., 2013).

Since the mid-1990's, the internet has emerged as a key element in transforming the discipline and process of cartography providing a faster method of map distribution in comparison to paper or CD-ROM formats. It has provided different forms of mapping and new areas of research (Cartwright et al., 2001). These developments in computer and communications technology have caused significant changes to take place in cartographic theory and production (Taylor, 2003). The role of the cartographer has changed to encompass these new challenges and possibilities. That said, these new possibilities do not eliminate the well-established challenges of effectively communicating and exploring geographic information traditionally addressed by cartographers. Indeed, they create new challenges (Pulsifer et al., 2005). One of the biggest challenges in regards to modern or interactive atlas creation involves handling large and heterogeneous quantities of statistical, geographical and image data nearly in real-time (Sieber et al., 2009).

2.1 Brief History of Atlases

Theatrum Orbis Terrarum, completed in 1570 by Abraham Ortelius, a Flemish geographer, is widely considered to be the first true atlas in a modern sense. He presented a collection of uniform map sheets and complimentary text bound to form a book (Buckley et al., 2003). Gerhard Mercator is credited with coining the term "atlas" in the title of his collection of maps published between 1585 and 1595 (Monmonier, 1981). Since then, atlases have been studied and produced. They provide people with a visual representation of their world and have encompassed a wide variety of topics. The atlas has been a window to the world for millions of people (Cartwright et al., 2007). Thematic collections of maps displaying physical and social themes have allowed readers to make comparisons between geographic scales and to examine potential processes that contribute to the observed patterns (Thomas et al., 1999).

The introduction of technology was revolutionary for the field of cartography. Not only did it transform the map creation process, manual compilation to computer-generated, but it brought forth a new medium for cartography (Ramos & Cartwright, 2006). Digital cartography has changed greatly over the past thirty years due to rapid advancements in computing technologies and the internet (Donohue, 2014). Technological advancements in cartography have affected atlas mapping as much as they have all other mapmaking activities (Buckley, 2003). This change has brought about many new differences in the way that atlases are now conceived, produced, disseminated, and used (Vozenilek, 2019).

The first digital atlases were developed during the eighties and an increasing research effort in the field has been carried out since then (Rystedt, 1996). During the last three decades, several national atlases have witnessed a revitalization in digital form (Sieber et al., 2009). Experts in the field have different opinions regarding which digital atlas was the first. Ramos and Cartwright (2006) consider the *Atlas of Arkansas*, presented in 1987 at the 13th International Cartographic Conference of the International Cartographic Association (ICA) to be the first digital atlas developed. The *Electronic Atlas of Canada*, produced in 1981, is considered to be first by Siekierska and Williams (1991). A third one, the *Digital Atlas of the World*, was created by Delorme Mapping Systems in 1986. Kraak & Brown (2005) consider the Delorme Mapping Systems digital atlas to be an extension of a paper atlas, as it is solely compromised of static maps via a menu. Early digital atlases faced challenges based on hardware limitations, such as storage capacity, and software, such as the lack of authoring tools for developing interactive applications (Ramos & Cartwright, 2006).

Since then, technology has continued to advance at a rapid pace, solving some of the hardware and software problems of the first digital atlases, but introducing new ones

as well. There is little reason to suspect this rapid advancement in technology will not continue (Donohue, 2014). Change is inevitable when it comes to maps and the internet (Peterson, 2008). Though the forms and functions of atlases have changed, certain aspects of excellence in atlas mapping have withstood the test of time and will likely persist into the future (Buckley et al., 2003).

2.2 Related Works

Various interactive atlases have been created over the years and the concept of an interactive atlas is not a new one. Much research has gone into not just interactive atlases, but also many types of digital mapping platforms. Research and development in dynamic, or interactive, atlases complements that in geovisualization, with both taking advantage of similar advances in computer graphics and interfaces but emphasising different audiences and goals (MacEachren et al., 2008). Similar ecological and biological mapping platforms have been created: The GIFT, Global Inventory of Floras and Traits, is a project that focuses on native species, as opposed to invasive species like the GloNAF (Weigelt et al., 2020). The Global Ant Biodiversity Informatics (GABI) project created antmaps.org to visualize large-volume biodiversity data using a client-server web-mapping application (Janicki et al., 2016). CropGIS, a web application for spatial and temporal visualization of past, present and future crop biomass development is another example of a web mapping platform used for biological and environmental purposes (Machwitz et al., 2019). The Atlas of Switzerland is a well-documented example of a thematic national atlas that was redesigned and transferred to the digital world in the late nineties. Since then, three editions have been published (Sieber et al., 2009). It is also the recipient of several national and international awards due to its interactivity functions and cartographic design (Sieber & Huber, 2007).

2.3 Atlas Theory Background

2.3.1 Atlas Theory

Atlases are probably the best known and most flexible cartographic product (Ramos & Cartwright, 2006). Though many definitions of atlases exist, almost all of them include the word "collection" or "combination". Atlases are not a set of randomly chosen maps (Vozenilek, 2019). Atlases are intentional combinations of maps or data sets, structured in such a way that specific objectives are reached (Kraak & Ormeling, 2010). Regardless of their medium, electronic or paper, atlases hold a unique position in cartographic communication. An atlas has the ability to tell a story. Like a novel, an atlas can lead you through an entire theme, for example, the historical development of a region (Buckley,

2003). Though atlases are frequently associated with concepts of "world" and "small" scale, there are atlases with large scale plans and special subjects as well (Keates, 1989). Whether it be a city, a region, a country, an ocean, or the world, an atlas presents a spatially and a thematically defined area (Borchert, 1999). They can be used for general reference, education, and business. Historically, atlases have played different roles - from instruments of power in the renaissance to current decision and planning support tools (Stefanakis & Peterson, 2006).

Atlases can accomplish an impressive and wide range of tasks. This is due to the fact that the value of atlases is based on two main principles: accessibility and relatability (Monmonier, 1981). These principles promote the creation of a product that is usable by people with the widest possible range of abilities and backgrounds. Information in an atlas is only valuable and useful if it is easily accessible. Atlases provide the organization to make maps, places, and data easy to find and read. Usability and ease of access are important features that distinguish an atlas from other cartographic products. Information provided in the atlas is only useful if it is accessible (Monmonier, 1981).

Atlases can be used for a plethora of different purposes. Because of this, it is necessary to further define the characteristics of different atlas types (Ramos & Cartwright, 2006). In 1989, Keates highlighted that one could generally discern atlas types by their scale, topic and target audience. Ormeling (1995) further classified traditional atlases regarding to their contents: geographical, historical, national/regional, topographic, and thematic atlases. On the basis of communication objectives, they can be classified as educational, navigational, physical planning, reference, and management/monitoring. These classifications can apply to digital atlases as well and examples of digital atlases for each of these classifications exist.

Digital atlases, also known as Atlas Information Systems (AIS) (Ormeling, 1995), electronic atlases (Kraak & Ormeling, 2010), or multimedia atlases (Hurni et al., 1999), combine the theory of traditional, paper atlases with modern technology. AIS encompass a wide range of features and technologies (Stefanakis & Peterson, 2006). They expand the potential for visualization by having the ability to provide more, different views of the same data due to superior storage capacities. The new technology allows for changes in classification, symbolization, or new color schemes. These concepts were not possible before on static maps.

Early on, Ormeling (1995) subdivided AIS into three types: view only AIS, interactive AIS, and analytical AIS. These three divisions were further defined by Kraak & Ormeling (1996, 2010). The first type, view only AIS, are just electronic versions of paper atlases. They provide no extra functionality and their definition and usage is almost exactly the

same as a paper atlas, except the user views it on a different medium. They do not benefit as much as the other types from the increased electronic potential (Ormeling, 1995). Interactive AIS are atlases that allow their users to manipulate the data sets contained. They allow the user to adapt the cartographic image of the data selected by the cartographer to one that matches their own view. The third type, Analytical AIS, expand on the Interactive AIS by not only visualizing the data in the atlas to the user's liking, but also selecting, deselecting, linking, and otherwise manipulating datasets as they please. Datasets can be combined and the full potential of an electronic environment is used. The user is not limited to themes selected by the atlas developer. Computations can be effectuated on themes and areas, and many GIS functions are available for this type of atlas. That said, the emphasis is still on spatial data accessibility and the visualization of said data (Kraak & Ormeling, 2010).

Analytical AIS begin to blur the line between a GIS and an AIS. GIS and AIS are both computer-based information systems that handle geographically referenced data, however, they both serve different purposes. Whereas GIS are computer assisted systems for the capture, storage, retrieval, analysis, and presentation of spatial data (Clarke, 1986), the emphasis of AIS is especially on the presentation of these data (Schneider, 1999). AIS often are bound to a specific area or topic and their emphasis is on the presentation of the data. Further differences are displayed in Figure 1.

	GIS	Atlas Information System
Use of Interface	Complex	Easy
Users	Experts	Non-Experts
Computing Time	Long	Short
Control by	Users	Authors
Main Focus	Handing of Data	Visualization of Topics
Data	Unprepared	Edited

Figure 1: Adjusted difference table recreated from Schneider (1999) showing differences between GIS and AIS

EarthExplorer, from the United States Geological Survey (USGS), is an example of a web mapping platform that is more similar to a GIS. This platform provides online search, browse display, metadata export, and data download for earth science data from the archives of the USGS. EarthExplorer has created a user interface for accessing large amounts of spatial data and has the goal of information retrieval and download. The map and cartography of the platform are not the focal point. EarthExplorer focuses on the utility over the usability. It is a collection of data, not a carefully curated selection of

maps with a related theme (Buckley, 2003). An atlas requires focus on the usability and accessibility of data. This is not to say that interactive atlases cannot have a high focus on utility. It means that atlases require a high level of usability and aesthetics as well.

2.3.2 Atlas Development

Digital atlas development has been studied extensively since the late 1980's. Modern digital atlases offer both high cartographic quality, user-friendly interfaces, and the potential to perform advanced spatial analysis (Schneider, 2001). Digital atlases have evolved from mostly view only AIS to now mostly interactive and analytical AIS. This transition affects not only how spatial information is displayed, but changes the fundamental way in which these atlases handle the data. Powerful interactive and analytical atlases should be able to analyze, process, and model multi-dimensional and spatio-temporal data. The visualization of these process must run in a well-informed way that considers sound cartographic principles (Bär & Sieber, 1999).

Since the transition to digital and the increasing abilities of technologies, much of the research regarding atlas development has involved incorporating GIS tasks within an atlas successfully. Three main strategies have been created for interactive atlas development based on different techniques. The first approach, Multimedia in GIS, relies on extending existing GIS with multimedia functionality (Bär & Sieber, 1999). This method is the fastest way to bring full GIS functionality into an atlas, as they are already built into the system, but it comes with a large visualization and usability cost (Moreno-Sánchez et al., 1996). By using a technical driven approach to the atlas development, emphasis is placed on the utility of the atlas as opposed to the usability. As the overall system is a GIS, limited multimedia functionalities exist. They often do not allow a system-independent overall atlas graphic design and lack integration of these powerful GIS tools with a user-friendly interface (Bär & Sieber, 1999). The first Electronic Atlas of Canada in 1986 was developed using this approach (Schneider, 1999).

The second approach, called GIS in multimedia, is almost the opposite. It attempts to integrate GIS functionality into a multimedia authoring system and is more flexible. The user interface can be designed independently of the GIS (Schneider, 2001). This approach focuses on communication, human-computer interaction, and media integration (Bär & Sieber, 1999). To integrate any analytical functionality, data structures, or GIS techniques, the developer must explicitly define and implement them (Schneider, 1999). This approach also has drawbacks. Though in theory, using a multimedia authoring system makes sense, many graphics software do not provide cartographic support (Bär & Sieber, 1999). This approach is also very labor intensive, as cartographic and GIS functions are individually designed and adapted to meet the specific needs of non-expert atlas users. Multimedia

systems also do not provide data structures that equally provide for high cartographic quality and GIS functionality (Schneider, 1999).

The third and most modern approach, coined GIS and Multimedia Cartography, is a variant of the GIS in multimedia approach. It is the approach adopted by the Atlas of Switzerland, a well-established cartographic product with a wide variety of usages and applications (Sieber & Huber, 2007). The goal of this approach is to overcome the cartographic limitations of the previous two approaches while preserving most of the analytical functionalities. This approach implies that an additional step is required in the process of preparing spatial data from GIS for use in an AIS. This makes sense, as the figure above shows that AIS should be showing edited and processed data. Cartographic generalization, symbolization, geo-referencing and map object identification can all be completed instead of showing users raw GIS data (Bär & Sieber, 1999).

By putting user interaction and perception before GIS functionality, the last two approaches adopt a more user-centered design (UCD) philosophy. Keeping the user in the forefront of visualization and interaction thinking, designing, and programming has proven to be successful in interactive atlas development (Sieber & Huber, 2007). UCD design principles will be further detailed in the Methods section.

In a broader sense, research and development into interactive atlases complements that of geovisualization. Both take advantage of similar advances in computer graphics and interfaces but emphasize different audiences and goals; geovisualization focuses more on support for research carrying out exploration and analysis while atlases focus on support for retrieving information and decision making (MacEachren et al., 2008). Technological advances in geovisualization usually mean technological advances in interactive atlases as well.

Interactive maps, the contents of most interactive atlases, fall under the umbrella of web cartography, which is the design, production, display, and use of maps over the internet (Black & Cartwright, 2005). Web mapping and web geovisualization are important aspects of interactive atlases, as interactive atlases are composed of web maps and utilize web cartography aspects. Because of this, web cartography design principles should be adhered and applied to interactive atlases. Tsou (2011) lists three design principles of web mapping that should be considered: User interface design, dynamic map content, and new mapping functions. These three principles can be used by web cartographers to design effective and intuitive cartographic representations on the internet.

2.3.3   Atlas Production

Web-based mapping applications are made up of mapping technologies, defined as the compilation of Application Programming Interfaces, frameworks, libraries, and services that altogether enable the creation and dissemination of web maps (Kraak & Brown, 2005). Though web mapping applications are typically made using three major components, spatial databases, web map servers, and client-side web technologies, the increasing abilities of modern web browsers has lowered the difficulty of client-side rendering, and modern web browsers can now be supplied with more features, such as minor geoprocessing algorithms (Padilla-Ruiz et al., 2019; Donohue, 2014). Large amounts of data can be not only rendered, but now analyzed in the browser. Client-side web applications use Hypertext Markup Language (HTML), Cascading Style Sheets (CSS) and JavaScript for their development. This is due to the growing spread of JavaScript in the development of web-based GIS (Farkas, 2017).

Many client-side mapping technologies exist today. Three popular ones, Leaflet, Mapbox, and OpenLayers are tile-based mapping libraries that produce slippy maps: maps based on sets of tiled images that load dynamically into the browser when they are needed (Sack et al., 2015). Slippy maps rose in popularity after the introduction of Google Maps and Google Earth in 2005. Google Maps established many technical foundations of web mapping that exist today (Li et al., 2011). All three of these mapping libraries are well documented and provide many usability benefits to both the user and the map developer. Leaflet especially is easy to learn, implement, and produce maps with a better "visual-look" (Padilla-Ruiz et al., 2019). Leaflet is also open source, meaning the source code can be viewed and extended to meet specific needs (Donohue et al., 2014).

Tile-based web mapping technologies do not handle projections other than Web Mercator well. Web Mercator, based on the well known Mercator projection, has been the defacto projection for almost all web mapping services since the rise of Google Maps and Google Earth in 2005. Since then, all almost web mapping services use Web Mercator as the default, and many times only, projection. Web Mercator is, in general, a good choice for online mapping due to technical reasons, however, cartographers and geographers have long discussed the inappropriateness of this projection for general purpose global-scale mapping (Battersby et al., 2014).

D3 is different from the majority of web mapping technologies currently available. It is increasingly recognized as one of the best data visualization libraries available for JavaScript, as it simplifies loading data and creating data interactions (Sack et al., 2015). Unlike tile-based technologies, D3 explicitly supports dynamic projection of linework into a wide array of map projections, using scalable vector graphics (SVG) to draw the

projected vectors in-browser (Roth et al., 2014). D3 is designed to support rendering of any interactive visualizations, not just maps. This can be incredibly beneficial, as it offers potential for multiview, coordinated geovisualizations with graphs and charts. It supports a broader use case, as maps are not the center focus of the library. D3, the previously mentioned mapping technologies, and many others, are more thoroughly reviewed by Roth et al. (2014).

Due to the popularity of slippy maps, such as Google Maps, many users have grown accustomed to the ability to zoom and pan endlessly on web maps. Depending on the age of the user group, usability requirements and experience with the internet and interactive maps in general might be different. Distinctions have been made on age and behavioral differences in the use of technologies and younger users, called "digital natives", are defined as those born in 1980 or later. Digital natives tend to be a major target user group for digital atlases (Schnürer et al., 2015) and optimizing the interactive atlas GUI towards them (i.e. making it more similar to web maps they are familiar with) could be an important factor in successful usability. Results from Schnurer (2015) showed that a layout most like Google Maps was attractive and successful for test users.

This idea of "digital natives" coincides with a concept called "paper thinking" coined by Peterson (1995). Paper thinking suggested that after centuries of static maps, mainly on paper, it would be hard for the paper atlas generation to overcome the way they were initially taught to conceive maps. As technology and interactive maps became ubiquitous, this obstacle should vanish, which it has for the newer generation. These concepts further solidify how important it is for the developer to know their target audience when adding interactivity methods to their atlas.

2.3.4 Atlas Challenges

The new electronic medium provides both new opportunities and new challenges. New geovisualization and cartographic challenges present themselves, but the same geovisualization and cartographic challenges with traditional atlases are still present. They include most geovisualization and map creation challenges, as atlases are a collection of these things. Great atlases require cohesion. They require a common theme that is pervasive throughout the atlas.

Cartography in the modern age deals with the complex process of geospatial information organization, access, display, and use with maps that are no longer conceived as simply a graphic representation of geographic space, but as dynamic portals to inter-connected, distributed, geospatial data resources. If well designed, the online map has the potential to be an interface that supports productive information access and knowledge construction

activities (MacEachren & Kraak, 2001). Emerging technologies have greatly expanded the possibilities of online, interactive maps, but these developments, however, now require cartographers to think about issues that used to solely fall in the domains of human-computer interaction and web design (Roth & Harrower, 2008). User interface design, as opposed to just map layout, is an increasingly important new challenge and skill set that the map creator must add to their toolkit.

Developing a comprehensive UCD approach to geovisualization usability is an interface challenge that was posed by MacEachren & Kraak in 2001, but keeping up with the rapid pace of technology has proven difficult in this regard. Due to these fast and constant changes, there are few tried-and-true guidelines for building digital maps (Roth & Harrower, 2008).

For the purposes of this thesis, Interactive AIS will be the focus. Cartographic interaction is what separates this atlas type from the others. Cartographic interaction is defined as how maps are manipulated by the map user. Map interactivity is among the most significant new possibility from the digital revolution of maps (Roth, 2013).

Interactivity provides great potential for digital atlases as they now have the ability to provide more accessibility and more information to the user. Digital environments allow for a broad array of interaction forms for manipulating cartographic products. Cartographic interaction, as defined by Roth (2013), is the dialogue between a human and a map mediated through a computing device. Interactive atlases, as expected from their name, use interactivity to enhance the experience of using an atlas. They allow users to adapt the cartographic image of the data selected by the cartographer to one that matches their own views (Ormeling, 1995).

Figure 2, a recreation of the goals of map use image from MacEachren & Kraak (1997), uses interaction as one the three axes that explain map uses. Atlases that want high exploration should allow for high interactivity, while those focusing on presentation should focus less interactivity. As digital atlases strive to obtain both high exploration and presentation, the challenge of balancing these opposing concepts becomes difficult.

One challenge is the possibility of allowing too much interaction to the user. This has the potential for the user, most likely a non spatial data expert, to create a cartographic data representation that is unappealing, unusable and takes away from a positive atlas experience. Actions and settings must be controlled by the authors to some extent to prevent the user from creating useless or erroneous maps (Schneider, 1999). The concept of restrictive flexibility, or allowing user exploration and interactivity within defined restrictions set by the developer, is a way to handle these interactivity problems while still giving the user the feeling of serendipitous exploration (Gartner et al., 2005).
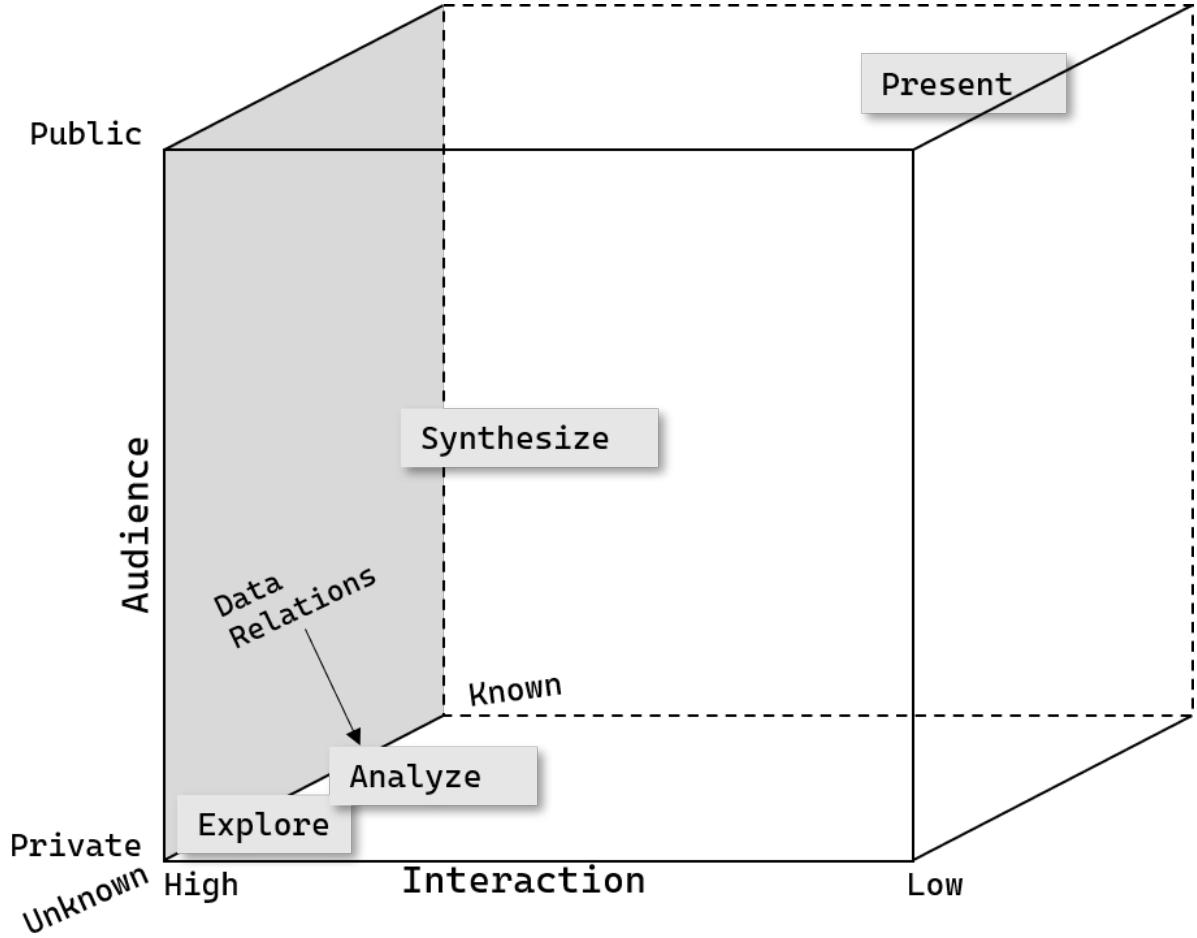
11

Figure 2: Recreation of the goals of map use from MacEachren and Kraak (1997).

3 Methods

3.1 Atlas Framework Background

In order to create an interactive atlas for the GloNAF dataset, a UCD framework can be utilized. Web cartographers can design effective and intuitive cartographic representation by focusing on the creation of user interfaces, mapping functions, and dynamic map content. UCD is considered essential for many web mapping projects (Tsou, 2011). An effective web-mapping application framework should be user-centered, but should also take into consideration the utility and usability of the application (Roth, Ross, & MacEachren, 2015).

A mixed approach to the interactive atlas development was created by combining the five stages of user-centered design approaches for web mapping applications put forth by Tsou and Curran (2008) and Roth et al.'s (2015) three U's for interface success.

The iterative five stages of user-centered design approaches for web mapping applications as laid out by Tsou and Curren (2008) are heavily adapted from Jesse James Garrett's website

design and implementation procedures (Garrett, 2002). Though many cartographers still view web mapping as a technical solution rather than an academic research topic (Tsou, 2011), it is hard to argue that the current role of cartographers does not include the creation of user interfaces as well as dynamic map content and mapping functions. The definition of cartographer has expanded and changed due to the modern trends in the field, and therefore it makes sense to adapt a user-centered design approach developed initially for website design.

There are five stages of user-centered design that can be applied to atlas creation (Tsou & Curran, 2008):

- **Strategy plane**: What do we want to get out of the site? What do our users want?
- **Scope plane**: Transformation of strategy into requirements: What features will the site need to include?
- **Structure plane**: Giving shape to scope: How will the pieces of the site fit together and integrate?
- **Skeleton plane**: Making structure concrete: What components will enable people to use the site?
- **Surface plane**: Bringing everything together visually: What will the finished product look like?

These five planes can be used for both user interface design and map contents. Figure 2 illustrates each stage and the example steps that would go into each plane for the GloNAF dataset. This figure also illustrates the dual aspects of web mapping: the user interface design and the map contents.

One important aspect about these five steps is that each development stage can be overlapping if necessary. For example, the structure plane can be started before the completion of scope plane. This is useful because if there are major changes in the design structure, those changes can be re-examined immediately on the scope plane and be appropriately modified on the structure plane (Tsou & Curran, 2008).

An essential starting point consideration for a UCD framework is determining how interface success is measured. Roth et al. introduces the three U's of Interface Success for interactive maps: Usability, Utility, and Users (Roth, Ross, & MacEachren, 2015). The relationship between the three U's is shown in Figure 3.

Usability and Utility are two concepts that have been greatly researched in the cartographic world, especially in regards to digital cartography and interactive web maps. Usability describes the ease of using an interface to complete the user's desired set of objectives (Grinstein et al., 2003). High usability seeks to reduce the time it takes to perform a

	User Interface Design	Display Layers
Surface	• Window arrangement and the use and design of icons, buttons, links for the user interface • Graphics for the main landing page	• Select symbols for maps • Select fonts and colors for map layers

Skeleton	**Grouping Functions**
	• Sidebar Panel
	  • Change Map Style
	  • Zoom to Continent
	  • Back to Home Button
	• Map Panel
	  • Hover Functions
	  • Click Functions
	    • Popups
	    • Zoom to Continent
		Arrangement of Map Layers
		• GloNAF Regions
		  • Continents
		  • Islands
		• Symbols for family/taxa count representation

Structure	**Formalized Function List**
	• Map Display Functions
	• Hover/Popup Functions
	• Query Functions
	• Change View Functions
	• Help Functions (if needed)
		Itemized Data Objects (Format)
		• GloNAF Regions
		  • Islands (CSV)
		  • Continents (GeoJSON)
		• Inventory, Supporting Taxa Information (CSV)

Scope	**Functional Specification** • Interactive map manipulation • Popup, hovers with relevant info • Query by Taxa, Family • Help and Instructions	**Data Content Requirement** • Display GloNAF Regions • Display Taxa Count, Family Counts • Display Inventory Completeness
Strategy	**Determine User Needs** • What do the GloNAF team members need from this atlas? • What do the target users want visualized?	

Figure 3: The five stages of a user-centered design approach for the GloNAF interactive atlas; modified from Tsou & Curran (2008).

routine task or limit the number of errors that might occur when solving a specific problem (Robinson et al., 2005). There are five measures of usability as listed by Nielsen (1992):

- **Learnability**: how quickly users understand the interface without prior use
- **Efficiency**: how quickly users can interact with the interface once learned to

complete the desired task

- **Memorability**: how well users can return to an interface and pick up where they left off
- **Error frequency and severity**: how often users make mistakes and how fatal they are, respectively
- **Subjective satisfaction**: how well the interface is liked by the users

Utility describes the usefulness of an interface for completing the user's desired set of objectives (Nielsen, 1992). By establishing benchmark tasks, or representative combinations of user objectives and information content, utility can be evaluated (Roth, Ross, & MacEachren, 2015).

Ideally, the cartographer would increase both the usability and utility to their absolute maximum. Increasing both the usability and utility of a web mapping interface can be achieved by improving the software and the user knowledge (Robinson et al., 2011). However, as the complexity and robustness of software increases, usability and utility tend to play out as competing forces (Robinson et al., 2011). This utility-usability tradeoff in web mapping is an important concept to consider. When creating a framework for interactive atlases, it needs to be structured to improve both usability and utility as much as possible through iterative interface refinement and user task analysis to determine what utility needs are required to accomplish the atlas' goals (Robinson et al., 2011). That said, there most likely will need to be sacrifices made. Arguably, the best way to resolve this trade-off is to seek input from the target user group. Identifying what tasks are important and not important to them can reduce unneeded functionality and identify missing functionality (Roth et al., 2013). Removing unneeded functionality can provide more usability, as unnecessary function buttons and designs will not take up space on the design.

This leads to the third "U": Users. Defining the target user group of your interactive map is necessary and an important process in all aspects of cartography, not only web cartography. The Users, or target user group, is defined by Roth as the community of users the interactive map is intended to support. An understanding of the user comes to define the initial functional requirements for the interactive map (Roth, 2015). The objective or function of the atlas is determined by the need (Aditya & Kraak, 2005).

The three U's of interface triangle can be applied to the five stages for a mixed approach to interactive atlas design. Applying this user → utility → usability relationship to the five stage framework can give the developer more ability to measure interface success. It also adds an iterative element to the five stage process. After a preliminary interface design and completion of the five stages, an interface evaluation can be sent out to target
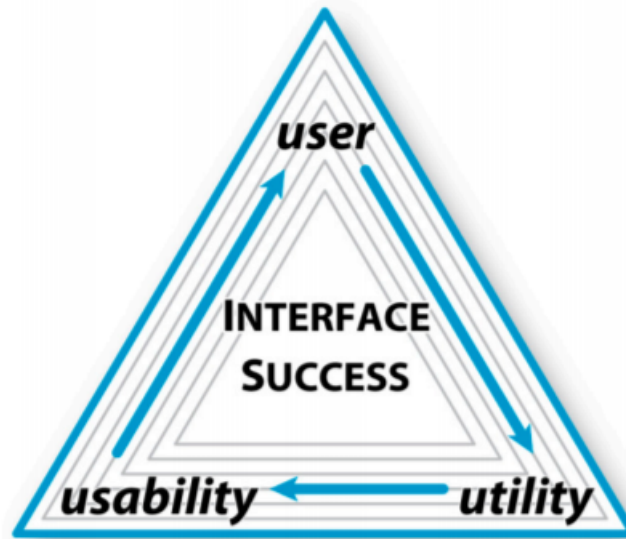
Figure 4: The three U's of interface success (Roth, Ross, & MacEachren, 2015).

users to gather feedback on the utility and usability of the atlas. The evaluation, which prompts a user → utility → usability loop, can then initiate another five stage process, as new information gathered from the users will result in updated utility and usability purposes. It is important to note too that this user → utility → usability loop can be instantiated at any step of the process if user feedback is received. Thus, it is beneficial to include the user at each step in order to gather new information and iterate through the user → utility → usability loop to update the atlas.

The concept of including the user at each step is not new, and is considered in many UCD web mapping processes (Robinson et al., 2005; Padilla-Ruiz et al., 2019). Other user-centered design processes were inspected and inspired the methods of this thesis. Robinson et al.'s (2005) UCD method discusses how user participation is important at multiple steps throughout the process. Rather than just getting user input after key decisions have been made by the developers, the users can be involved in various steps to help prevent time consuming and large over-arching updates (Robinson et al., 2005). Slocum et al. (2003) discusses how getting the "decision makers", or target users, involved earlier would have been beneficial. In their study, the authors chose not to involve the users earlier because they believed that a more polished product was needed to show to the users for the first time. This leads to the belief that showing a fairly unpolished product, one that is not perfect, to the target user group early on can be beneficial for all parties. The developers can get a better understanding of how the users will use the atlas and interact with it if their input is received early on in the process.

The following mixed five step approach is an attempt to incorporate successful parts and steps of tested web map development processes in order to create an ideal framework that will result in a usable and successful interactive atlas. This mixed approach to interactive

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atlas design is also an attempt to address the interface and cognitive/usability goals outline by MacEachren and Kraak (2001) and better achieve a useful product for the target user group (Robinson et al., 2005).

3.2 Stage One: Strategy

This stage involves defining both the target users and their needs. This would further clarify and determine what the goals and objectives of the GloNAF interactive atlas are. Achieving success with the interactive atlas, and in any geospatial technology, must recognize the differences between the wide range of users of this field (Haklay & Zafiri, 2008). Familiarity with maps, the internet, and the source data are all factors that need to be accounted for when considering usability. Knowing the users background can be helpful in determining utility and usability features.

In consideration of the target user group, there are four axioms that the designers and developers should embrace as they begin to learn their audience (Roth, Ross, & MacEachren, 2015). First, domain experts do not necessarily represent target users, as they often hold more experience and knowledge than the typical user. Second, the target users are unlikely to know what they want when first contacted, meaning that it is the job of the cartographer to translate their requests into tangible functional requirements (i.e. stage two of this framework). Third, the target users are likely to evolve over time, and therefore the interface should evolve with the target users. Finally, the target users can be diverse in their ability, expertise, motivation, and knowledge of their domain and interactive map use.

Determining the needs of the user can be done through several approaches. Various knowledge elicitation techniques exist, including interviews, focus groups, or questionnaires and surveys. Questionnaires and surveys are especially efficient and useful when the investigator starts with a sufficient background knowledge of the domain and knows what questions to ask (Robinson et al., 2011). Survey questions are usually close-ended to generate information on specifically identified topics, and the response format can include ranked responses and the identification of multiple items of interest (Dillman et al., 2014). They are also a good method when the investigator cannot be physically present to administer the evaluation and input is required from a large number of diverse users (Roth, Ross, & MacEachren, 2015). Focus groups generally involve between six and twelve people who gather to discuss a particular topic under the direction of a moderator, who promotes interaction among participants and ensures that the discussion remains on topic (Stewart & Shamdasani, 1990). Questions are generally developed beforehand by the developer to explore specific goals or validate prior assumptions (Kessler, 2000). This method is especially useful when the user needs and expectations are poorly known (Roth,

Ross, & MacEachren, 2015). Another qualitative method that is useful to cartographers is interviews. Interviews are also useful when the needs and expectations of the users are poorly known. They are useful in obtaining users' reactions to software, as the interviewer can steer the interview based on the user's responses (Slocum et al., 2004).

In order to determine the needs of the GloNAF core team, a general four question questionnaire was created to gather their feedback. Our questionnaire wanted to determine which data in the GloNAF dataset the target users were most interested in having visualized. Figure 5 shows the questions asked. A questionnaire was used due to the fact that the team is spread out between multiple universities and different countries, and an online questionnaire was the most efficient way to gather feedback from everyone.

Questionnaire:

1) Is there any specific data in the GloNAF Dataset that you are interested in seeing visualized? (ex. Counts of taxa per tdwg region? Families per region? Mapping where a specific plant is invasive? Naturalized vs. alien for a region? Visualizing inventory completeness?)

2) Would a data download feature be useful?

3) If yes, I know there is a main focus on global patterns, but would a feature that lets a user download data for specific regions or taxa be useful? (ex. If you were only interested in Hawaii you could download that data only, or if you were only interested in one plant/taxa/family you could download just that information)

4) Would having multiple map views at the same time be useful? This would give the possibility for comparisons between different regions.

Figure 5: The questionnaire sent out to and answered by the target user group.

3.3   Stage Two: Scope

This stage involves translating what the target users want into tangible goals. By doing so, stage two establishes the scope of the interactive atlas. Tsou and Curran (2008) describe the two aspects of this stage: functional mapping specification and map content requirement. Function mapping specification refers to the identification of the major mapping tasks as determined by the user needs and map objectives, which were defined in stage one. The map content requirement includes the data required for the web mapping platform.

3.4   Stage Three: Structure

This stage involves the formalization of the mapping functionalities of the atlas. It is necessary to create a list of tools needed to accomplish the tasks of the atlas. Examples

of these functionalities include spatial queries, buffering, and help functions. These functionalities are determined through analysis of the users' needs in steps one and determining what can accomplish the map objectives compiled in stage two. Extensive atlas research and a competitive analysis of similar thematic web atlases and web maps can help to achieve success in this stage. A competitive analysis is a usability engineering method administered to critically compare a suite of similar applications according to their relative merits. It is a theory-based method based on secondary sources that critically compares a suite of related applications according to their relative merits (Nielsen, 1992). The competitive analysis method may especially be beneficial when the design and development team knows little about the application domain (Roth, Quinn, & Hart, 2015). It can be used to discover trends and gaps within these applications, which could lead to new opportunities for development (Padilla-Ruiz et al., 2018). Given the pace of technological change in web mapping, it is considered essential to complete a competitive analysis for most web mapping applications (Roth et al., 2013). Therefore, it is recommended that the framework include a competitive analysis in stage three as it can help the developer find state of the art interactive atlases to draw inspiration and ideas from. Stage three also consists of itemizing the atlas data contents. A complete, more formal list of data needed based on stage two will be developed. While itemizing and collecting the data needed, synchronously itemizing your data challenges is recommended.

3.5   Stage Four: Skeleton

The skeleton stage involves the arrangement of data objects into meaningful categories. It also includes the design of the overall structure and display of the atlas; elements such as the map display window, the sidebar menu, and the pop-up windows. Valuable segmentation, the appropriate division of the screen surface (Cartwright et al., 1999), is important. Since an atlas is understood to be a compilation of maps, the map should always be the main part of the web page. To further visualize atlas at this point, a wireframe will be created. A wireframe is a rough visual outline of a proposed application (Lloyd, 2009). It is a specific kind of prototype generated during the user-centered design process that can be used to collect input and feedback from target users before designs are finalized. Prototyping in general has been identified as essential for incremental improvement to the utility and usability of an application, especially in cartography. Wireframe prototypes have been proven to be valuable in both research and development. They can save project time and resources if used early in a user-centered design process (Roth et al., 2017).

Layer Management is an important implementation step as well. It requires intelligent and thought out data management (Cartwright et al., 1999). As the user will be activating

and deactivating layers on their own, it is important to keep things in mind such as opacity, organization, and hidden layer aspects. Opacity is important in the sense that if two layers are activated, they should both be visible. If one layer is on top of the other, the top layer needs to be styled so that it correctly displays itself and the layer below. Organization involves the layer ordering; knowing which layers load first or appear first in the interface. Knowing which layers will load below or above other layers is necessary as well. As this might depend on the user interaction, all possibilities need to be thought out. Hidden layer aspects deal mostly with click or hover interactions. Thematic information on a region might not appear on a selected layer, however, it still might be required for a click or hover popup interaction information window. A way to access underlying layers, or layers not on the top, is important and necessary for successful interaction.

3.5.1 User Test

After the creation of a wireframe prototype, a user test was sent out to gather feedback on the atlas. It tested the utility and usability of the interactive atlas at this stage. The user test was administered via the web for the same reasons as the user needs assessment in stage one. This user test will help the development as it will allow the cartographer to make early changes to the atlas before it is fully completed. It also initiates a user → utility → usability loop, which can bring meaningful updates and contribute to a successful atlas.

As noted as being acceptable in the Atlas Framework Background section, a few surface stage aspects were completed before entirely finishing the skeleton stage. This overlap is necessary in order to bring the atlas usability up to an adequate standard. It also can be useful to gather initial feedback on color choices. Questions were divided into utility questions and usability questions. The utility questions assessed the ability of the interactive atlas to be a resource for GloNAF related questions. The usability questions gathered feedback on ease of use, learnability, and the overall opinion of the atlas by the users.

To answer these questions, the users will open the interactive atlas prototype and figure out the answers to the questions. This tested the utility of the atlas and determine if it is a useful interface for completing the user's desired set of objectives. Figure 6 displays the utility questions.

The next questions measure the usability of the atlas. Usability will be measured by asking about ease of use and learnability of each view. The questions will also measure the users subjective satisfaction with the prototype. These are shown in Figure 7 and Figure 8.

These questions measure the utility of the atlas. After taking a moment to familiarize yourself with the atlas, answer the questions however possible.
If the maps are too large for the screen, please let me know in the comments in the end. A workaround for this is to zoom out in your browser.

2. How many Taxa are in Japan?

[   ]

3. What is the Completeness of California?

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ I don't know

4. For the Solanaceae family, can you name a region with more than 50 members?

[   ]

These questions measure the utility of the atlas. After taking a moment to familiarize yourself with the atlas, answer the questions however possible.
If the maps are too large for the screen, please let me know in the comments in the end. A workaround for this is to zoom out in your browser.

5. Can you name a region where Solanum melongena is naturalized?

[   ]

6. Can you name a region where Solanum melongena is alien?

[   ]

7. On the African continent can you name a region with the highest level of completeness?

[   ]

8. For the region Florida (in the United States), can you determine the number of members of the Polygonaceae family?

[   ]

Figure 6: Utility Questions

3.6   Stage Five: Surface

The final stage is the surface stage. The surface stage is arguably the most important stage of the framework. This stage focuses on bringing everything together visually and finalizing the atlas. The actual design of the web map user interfaces and incorporation of all map contents is completed. The design of graphic icons, buttons, and window layouts are major parts of this stage. Map symbology, fonts, and color schemes for different map layers are also completed during this stage.

When completing the surface stage, it is important to test the visuals on multiple web browsers. Three popular browsers, Google Chrome, Mozilla Firefox, and Internet Explorer

9. How easy was it for you to answer these questions?

○ Difficult   ○ Not Easy   ○ Neutral   ○ Moderately Easy   ○ Very Easy
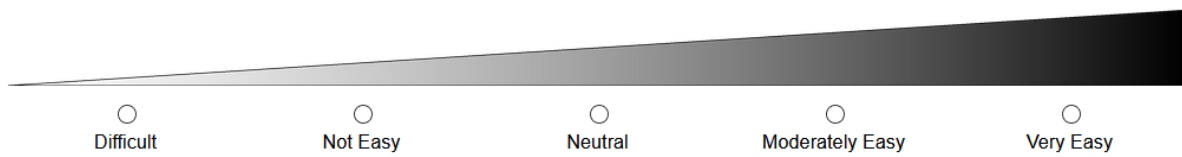
10. Overall, do you find this atlas layout visually pleasing?

○ 1 – Not Pleasing at all   ○ 2   ○ 3   ○ 4   ○ 5 – Very Pleasing
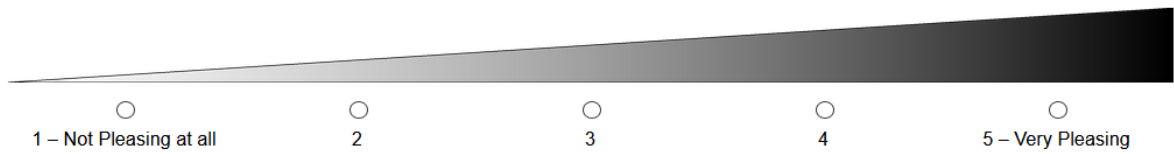
11. Which View was the easiest to use?

○ World View
○ Plant View
○ Continent View

12. Which View was the most visually pleasing?

○ World View
○ Plant View
○ Continent View

**13. Which View did you use to answer most of the questions?**

○ World View
○ Plant View
○ Continent View
○ Even mix of all three

Figure 7: Usability Questions

will be used to test the fonts, colors and usability of the atlas.

Implementation wise, interactive atlas creation draws upon and is similar to web-based mapping application creation. Development of the GloNAF interactive atlas will focus mostly on client-side technologies, as geographic data will be queried and indexed in the browser. The interactive atlas for the GloNAF dataset will consist of various interactive web maps. D3 will be used due to its flexibility regarding projections. The interactive atlas will not have to depend on Web Mercator, and the projection can be changed to best visualize the part of the world that the user focuses on. Cartographic design is paramount in atlas design, and D3 allows the atlas utilize equal area projections that are a better representation of the world at a global scale. D3 also handles large datasets well. It can easily use both CSV and GeoJSON data types.

14. How easy was it to learn how to use the continent view interface?

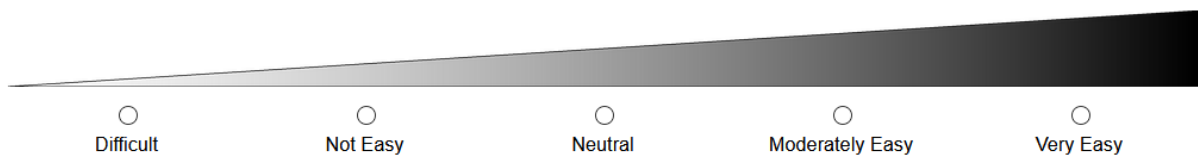| ○	○	○	○	○
Difficult	Not Easy	Neutral	Moderately Easy	Very Easy
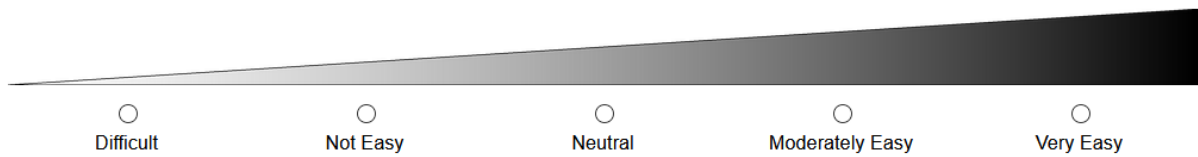
15. How easy was it to learn how to use the world view interface?

○	○	○	○	○
Difficult	Not Easy	Neutral	Moderately Easy	Very Easy
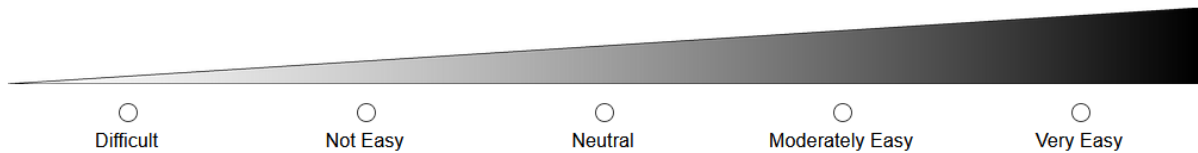
16. How easy was it to learn how to use the plant view interface?

○	○	○	○	○
Difficult	Not Easy	Neutral	Moderately Easy	Very Easy

17. Did any view, visualization, or color scheme seem unclear or difficult to understand?

Figure 8: Usability Questions Part 2

4 Results

The developed framework created is displayed in Figure 9. The results section is divided to explain the results from the developed framework at each stage.

4.1 Stage One

For the GloNAF interactive atlas, the target audience was the GloNAF core data team. The GloNAF core data team is an interdisciplinary group of scientists from Germany, Austria, and the Czech Republic. Though interdisciplinary, most come from a background of biology or ecology (Kleunen et al., 2019).

4.1.1 Questionnaire Results

The web-delivered questionnaire was answered by eleven people (the GloNAF core team consists of eleven people) and the results were analyzed. Question one was open-ended. Questions two, three, and four had the answer choices of "yes" or "no" with a comments section below. The responses for question one were varied, however, four responses
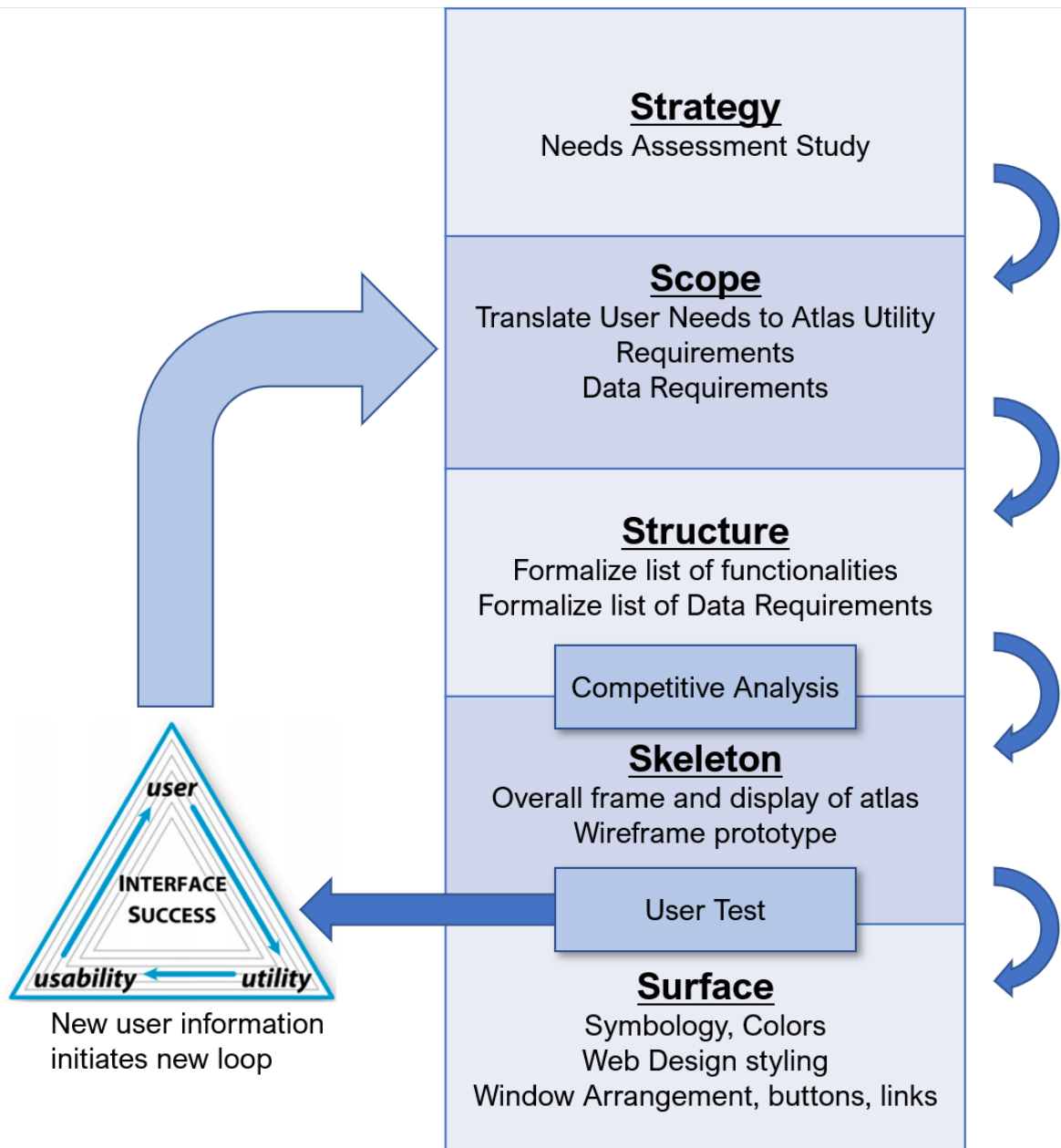
Figure 9: The developed framework for interactive atlas creation. The competitive analysis and user test illustrate the overlap that is allowed to happen between steps. The competitive analysis benefits the development in both stage three and four, while the user test required a prototype with basic styling (stage five).

indicated their interest in the examples mentioned in the question itself. A further two specified their interest in inventory completeness. Other responses included maps showing naturalized versus alien species, species distribution, where a specifics plant is invasive/naturalized to, and maps with the ability to toggle to different taxonomic scales (species, genera, families).

Ten out of eleven answered "yes" for question two. Four comments were made to this question, and two of those comments raised concerns about keeping the data up-to-date,

as the GloNAF dataset is still being updated regularly. Question three, dependent on question two, received eleven "yes" votes. Question four received nine "yes" votes. Out of four comments, two were positive. One comment indicated that comparison maps would be useful for comparing naturalized and native diversity, and also comparing the naturalized distribution of two different families. The comments that were not directly positive were not completely negative either. One comment was unsure if this would be a useful feature and another said it "would not be needed, but be good."

4.2   Stage Two

Translating the results of stage one into tangible visualization goals and concepts is the main objective of stage two. It is important to understand that a survey's results cannot be used as the only factor in the decision making process. Important design decisions should not be based solely on upon the results of a survey (Roth, Ross, & MacEachren, 2015). Cartographic expertise is vital in this stage to help keep the atlas goals realistic and achievable. Knowledge of data manipulation, geospatial technology, and data analysis are all skills that help the developer manage expectations, time, and complete the atlas successfully.

For the GloNAF interactive atlas, the major tasks include interactive map manipulations, querying attributes, specifically families and taxa, and styling maps based on attributes. Major things to visualize include counts of taxa per Taxonomic Databases Working Group (TDWG) region, families per region, and mapping where a specific plant is invasive to. One of the main goals of this atlas is to further the ability of the GloNAF dataset to visualize global and regional patterns of plant invasions. Mapping the spatial distribution of plant families, taxa, and species is a way to help further this ability.

This stage also involved gathering of the necessary data. The GloNAF dataset is provided in a shapefile and four accompanying comma-separated values (CSV) files. The Geo JavaScript Object Notation (GeoJSON) is a standard web format for web mapping, so the shapefile will be converted into a GeoJSON (Butler et al., 2016). The CSV's can be read by JavaScript, so they will be processed and kept in the same format. Along with the GloNAF dataset, a global GeoJSON file of countries will be needed as well. This was obtained from Natural Earth data, an open source data storehouse supported by the North American Cartographic Information Society.

4.3   Stage Three

The structure stage is where the conceptual development began of the atlas. Concrete sketches of the atlas designs, or graphical user interface (GUI) elements, were created.
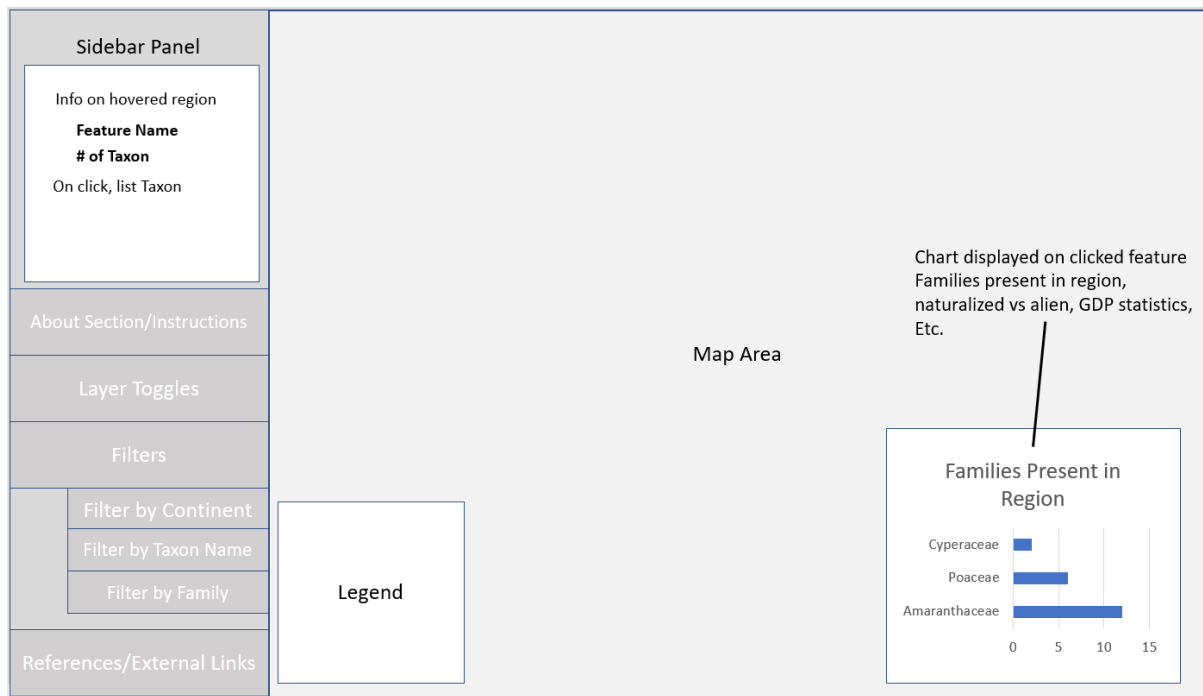
Figure 10: A Wireframe prototype of the interactive atlas.

The concept of a wireframe was invoked as well to better visualize the overall structure of the atlas on a screen.

Figure 10 shows the basic wireframe of the atlas views. The view is divided into two main parts: the map area and the sidebar panel. This sidebar and map area division is a common theme among mapping platforms. It can be seen in many major web atlases, including the Atlas of Switzerland and the ÖROK Atlas Online (Lechthaler et al., 2006). These panels are consistent throughout each map view. This design allows for the map area to take up most of the space on the screen, and a left hand sidebar panel will be available that contains buttons, help functions, and text information. A legend will be visible in the bottom left of the map area, and popup windows for hovering and click interactive events will appear as well.

A decision was made to divide the atlas into three sections: World View, Continent View, and Plant View. The views would be accessible through a homepage, functioning similar to a table of contents. This decision was made to better structure the users' interactions with the data. The visual information seeking mantra "Overview first, zoom and filter, then details-on-demand" was kept in mind during this decision. Exploring information collections becomes increasingly difficult as the size of data grows, therefore, the separation attempts to address this issue by segmenting the data (Shneiderman, 1996). Another reason for separation, especially for the world view and the continent view, was to better address the issue of geographic scale. Geographic scale is a unique geospatial characteristic of spatial data that makes it different from other kinds of data

and information (MacEachren & Kraak, 2001). It is a critical but complex issue, and especially important for the GloNAF dataset. The GloNAF dataset was compiled to assist in plant invasion and biodiversity research at the global and regional scale. Visualizing global patterns and regional patterns can be accomplished successfully by separating the tasks to make it easier for the target users to view the scale-dependent phenomena and patterns. As the dataset is large, it also gives the user the ability to filter out the data they do not need.

4.3.1 Competitive Analysis

For part of the structure stage, a competitive analysis study was completed; other biodiversity web mapping platforms and online atlases were viewed to gather information on their specific strengths, weaknesses, and methods. Though not self-defined as atlases, the Map of Life (Jetz et al., 2012), Ant Maps (Janicki et al., 2016), and the GIFT (Weigelt et al., 2020) were included due to their ecological and biological visualizations. Comparing and viewing relevant geovisualization examples within the same field as the GloNAF dataset can provide benefits to see what map types or interaction methods are most used by scientists in those disciplines. This analysis can also help answer the third research objective, as the results can provide provide insights into patterns or similarities between functionalities across different atlases.

Representation methods, interaction methods, and the technology stack of each web mapping platform were compared. Representation is described as the way the information on the map is encoded. Use of animations, legends, landing pages, and non-Mercator projections were compared. The representation section also includes thematic map types to see if one type is more popular than another. As atlases historically include visualizations of time and use non-map data visualizations as well, it was deemed important to compare those topics as well.

Interaction is defined as the ways a user can manipulate the map. Some categories for interaction types were borrowed from Roth et al.'s (2014) study comparing different web mapping technologies. Though Roth's study had a slightly different focus, some of the categories derived for their competitive analysis could be utilized in our study as interaction methods, such as Pan, Filter, and Zoom (Roth, Quinn, & Hart, 2015).

The technology stack will also be compared to see what other atlases and web mapping platforms are using to develop their systems. The analysis will compare what mapping libraries are used, if a database is used for storing the data, and if a download data button or section is included in the interface.

The results are displayed in Figure 15. It is important to note that low scores in this

Web Mapping Platform	URL	Basic Description (from source)
GIFT	https://gift.uni-goettingen.de/home	A global archive of regional plant checklists, floras, plant functional traits.
Gender Atlas of Austria	http://genderatlas.at/	Atlas visualizing data, indicators, and information on the realities of women & men in Austria.
Map of Life	https://mol.org/	Geographic Information visualizations describing species distributions worldwide.
Ant Maps	https://antmaps.org/	The goal of antmaps.org is to provide an intuitive and efficient framework for professional and amateur myrmecologists to visualize the known distribution of ant species or higher taxon, and to access the underlying records for those data.
Allen Coral Atlas	https://allencoralatlas.org/atlas/	The Allen Coral Atlas goal is to take high resolution satellite imagery and advanced analytics to map and monitor the world's coral reefs in unprecedented detail.
Atlas of Switzerland	Download link: http://www.atlasderschweiz.ch/portfolio/aos-online/	The Atlas of Switzerland Online is a complete atlas framework covering a wide range of categories.
Atlas of Biodiversity Conservation in the Coral Triangle	http://www.marine.auckland.ac.nz/CTMAPS	The atlas of the Coral Triangle showcases all of the currently available marine biodiversity conservation data for the Coral Triangle region
Fish Atlas of Germany and Austria	https://biodiv-atlas.de/fish/#!/home	An atlas of fish species in Germany and Austria.

Figure 11: This figure displays the name, url and a basic description of the web mapping platforms included in the competitive analysis.

Figure 12: Results of the interaction section of the competitive analysis.

Figure 13: Results of the representation section of the competitive analysis.

Atlas	Representation											
	Visualize Time	Animations	Choropleth Maps	Graduated Symbol Maps	Dot Distribution Maps	Heat Maps	Legend	Landing Page	Help Section	Emphasis on Visualizations	Non-Map Data Visualizations	Non-Mercator Projection
GIFT	Red	Red	Green	Red	Red	Red	Green	Green	Red	Green	Red	Red
Gender Atlas of Austria	Red	Green	Green	Red	Green	Red	Red	Green	Green	Red	Red	Red
Map of Life	Red	Red	Green	Red	Green	Red	Green	Green	Green	Green	Red	Red
Ant Maps	Red	Red	Green	Red	Red	Green	Green	Red	Red	Green	Green	Red
Allen Coral Atlas	Red	Red	Green	Red	Red	Green	Green	Green	Green	Green	Green	Red
Atlas of Switzerland	Green	Red	Green	Green	Red	Red	Green	Green	Green	Green	Green	Green
Atlas of Biodiversity Conservation in the Coral Triangle	Red	Red	Green	Red	Red	Green	Green	Green	Red	Red	Red	Red
Fish Atlas of Germany and Austria	Red	Red	Red	Red	Green	Red	Green	Green	Green	Green	Green	Red

Figure 14: Results of the technology section of the competitive analysis.

Atlas	Technology		
	Database Used	Data Download	Mapping Library
GIFT	Green	Red	Google Maps API
Gender Atlas of Austria	Red	Red	D3.js
Map of Life	Green	Red	CARTO & Google Earth Engine
Ant Maps	Green	Green	D3.js + Leaflet.js
Allen Coral Atlas	Green	Green	Mapbox & Google Earth Engine
Atlas of Switzerland	Green	Red	C++ (Must Download to Computer)
Atlas of Biodiversity Conservation in the Coral Triangle	Red	Red	ArcGIS Online
Fish Atlas of Germany and Austria	Green	Red	Leaflet.js

analysis do not necessary correlate to a bad atlas or a bad web mapping platform. The competitive analysis does not take into consideration the target audience of each atlas or the specific goals that each atlas is trying to reach. As discussed above, atlases cover a wide range of use cases, and the target audience might have preferred certain visualizations or interaction methods.

The representation results showed that choropleth maps are the most popular map type of the web mapping platforms compared. Graduated symbol maps and dot distribution maps were used as well, but not as much as choropleth. Heat maps are a map type that is not well represented in atlases, as only the Atlas of Biodiversity Conservation in the Coral Triangle used that thematic map type. Animation was only used in two subjects and the use was for transitions. For example, in the Gender Atlas of Austria, animation is used for a zoom effect when you click on a region or for transitioning a thematic map to another data visualization, such as a bar graph.

The interaction results showed that more GIS type interactions are mostly left out of digital and web atlases. Reexpression, or the idea of allowing the user to visualize the same data in different visualization methods, is unavailable for all the atlases compared. Resymbolize, the ability to change the number of classes used in a choropleth or graduated symbol map (Roth et al., 2014), is also not possible. Reproject, the ability to change map projections, is also not available in the atlases that were examined. As noted in section 2.3.4, Atlas Challenges, it is possible theses interaction methods give the users too much freedom with the data. The goal of atlases is to provide processed data to the users in a visually pleasing way. Many atlas users are not spatial data experts, and giving control over visualization types and methods increases the possibility of errors and misinterpretations. Not only that, but it would also increase the learning curve and therefore detract from usability.

More basic interaction methods, such as panning and zooming were included in almost all web mapping platforms. Search functions and the ability to filter data were included less often. All maps allowed for the ability to change the basemap to a different style, including one that showed satellite imagery, except for the Gender Atlas of Austria.

The Atlas of Switzerland, a realized complete atlas framework building on over two decades of research and development, had the most amount of representation methods and interaction methods. This result did not surprise the developer, as the Atlas of Switzerland is held in high regard by the cartographic community and the recipient of many International Cartographic Association (ICA) awards. The atlas is the only one from the study that is not on the web. It requires the user to download it to their computer which has the benefit and more computing power for data processing, interaction, and visualization.

One notable result from the analysis was the diversity of web mapping libraries used. This demonstrates that there are many current web mapping technologies available that can accomplish the goals of creating an interactive web atlas. Most of the atlases inspected use a database to host the data in as well.
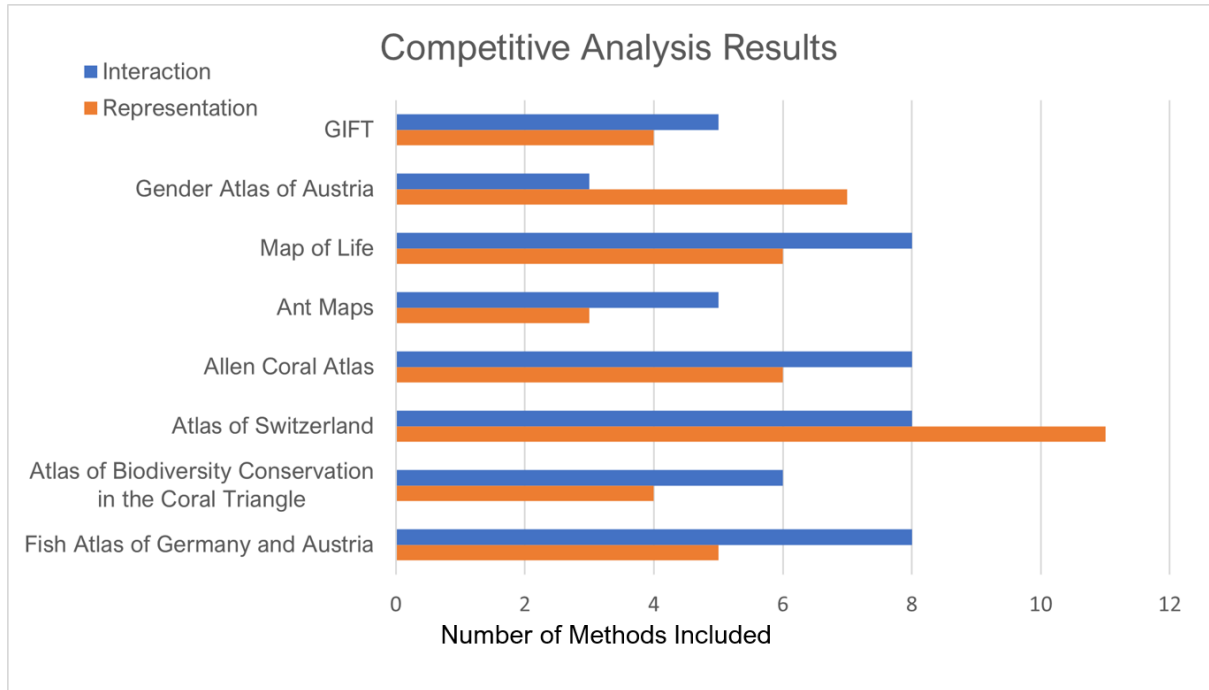
Figure 15: Results of the competitive analysis by atlas. This graph shows the number of boxes checked for each atlas.

4.3.2 Data Challenges

The GloNAF dataset provides some visualization challenges. It encompasses 1,029 geographic regions over the entire earth, of which 381 are islands. The regions are loosely based on the TDWG regions (Brummitt, 2001). Since a small scale is needed to visualize the entire world, making sure to appropriately represent these small areas equally with larger areas is a challenge. The regions themselves are not regular; some represent entire countries, while some are just one small island of a larger island country or state. For example, the state of Hawaii is broken up into eighteen different regions, while the entire country of Indonesia is just one. Most areas have no overlaps, however South America, especially Chile, has many overlapping regions. This makes it difficult to accurately show all data, especially at a small scale. Cartographic generalization must be used in order to simplify the overlapping areas.

Within the dataset, there are a fair amount of topographic and spatial quality issues. However, the issues are not homogeneous, but heterogeneous in their distribution. This is due to the data most likely being gathered at different scales from multiple sources. One example, detailed in Figure 16, shows the spatial quality issues. The fact that the data was collected at multiple scales led to data exploration challenges. One large advantage of digital atlases is their ability to allow for high levels of exploration (Borchert, 1999), however, due to the data quality, exploration was restricted to make sure the user could not zoom in too far to notice the issues. Zooming was also limited so that the user did

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not waste effort in zooming for no purpose. For most continents, states are the smallest region, meaning that zooming closer than the starting visualization would add no value.
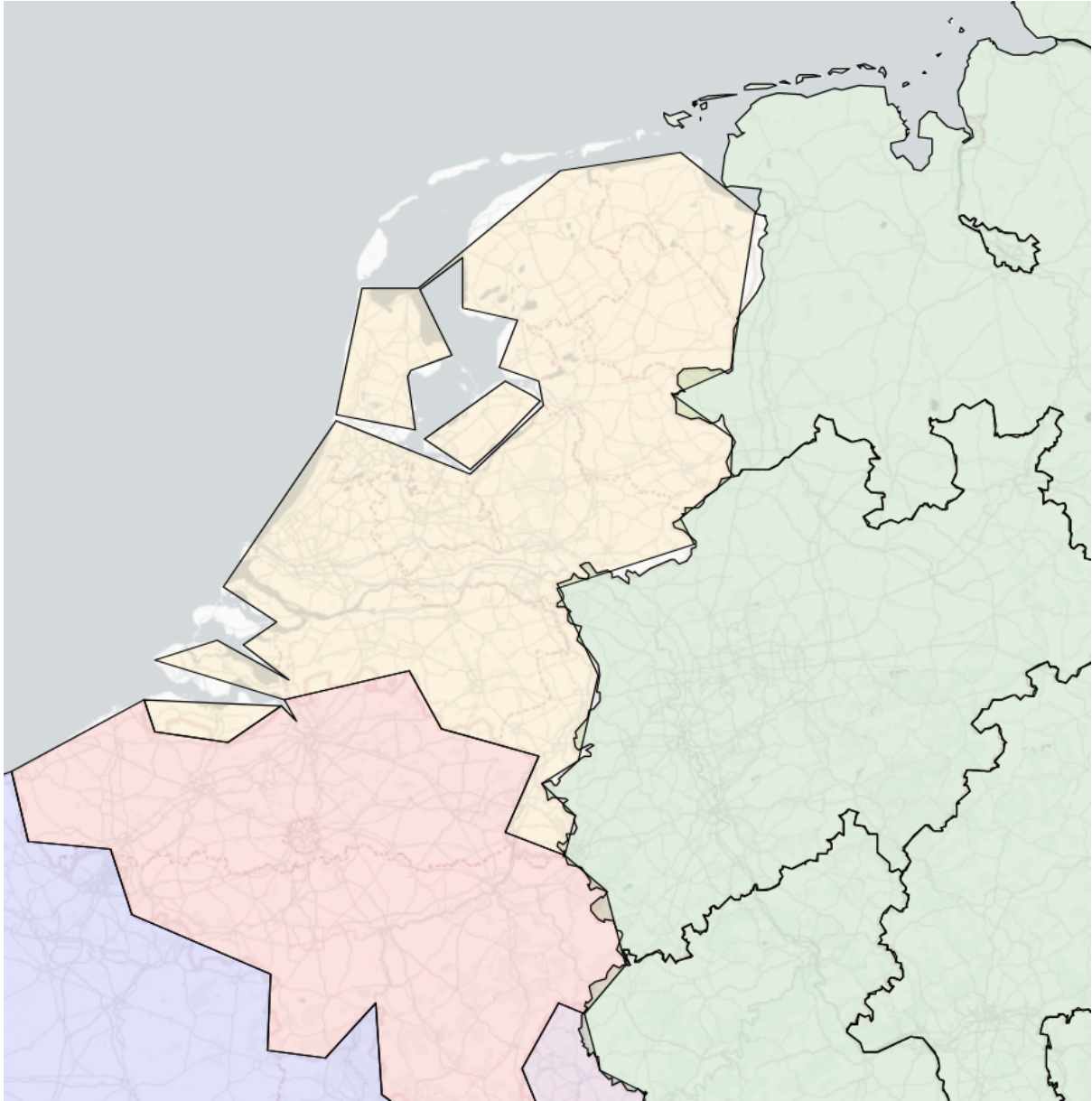
Figure 16: This figure shows the difference in border quality that is common throughout the dataset. The Netherlands (yellow), Belgium (red), France (blue), and Luxembourg (purple) have simplified borders, while the German (green) states have more detailed boundaries and do not topographically line up with the others. The base map shows that The Netherlands boundary is too simplified and not that accurate.

As this dataset represents the entire world, it is understandable that small scale data is used. High level detail is not entirely needed for this use case, and the scale differences cause inconsistencies that lead to quality issues as shown in the figure above. The next figure below shows another example of the inconsistency. The region of Tonga is accurately digitized and well detailed, however, the overall size of Tonga is small, as shown in Figure 17. Each island is roughly one kilometer. Though it is well detailed, most likely this

polygon will be represented as a dot due to scale issues. Because of the use of a small scale for the atlas, high detailed polygons tend to increase our data size without providing value. This is another issue most likely derived from the combination of multiple data sources. Fixing these inconsistencies and aligning the dataset to itself could be a possible future work consideration.
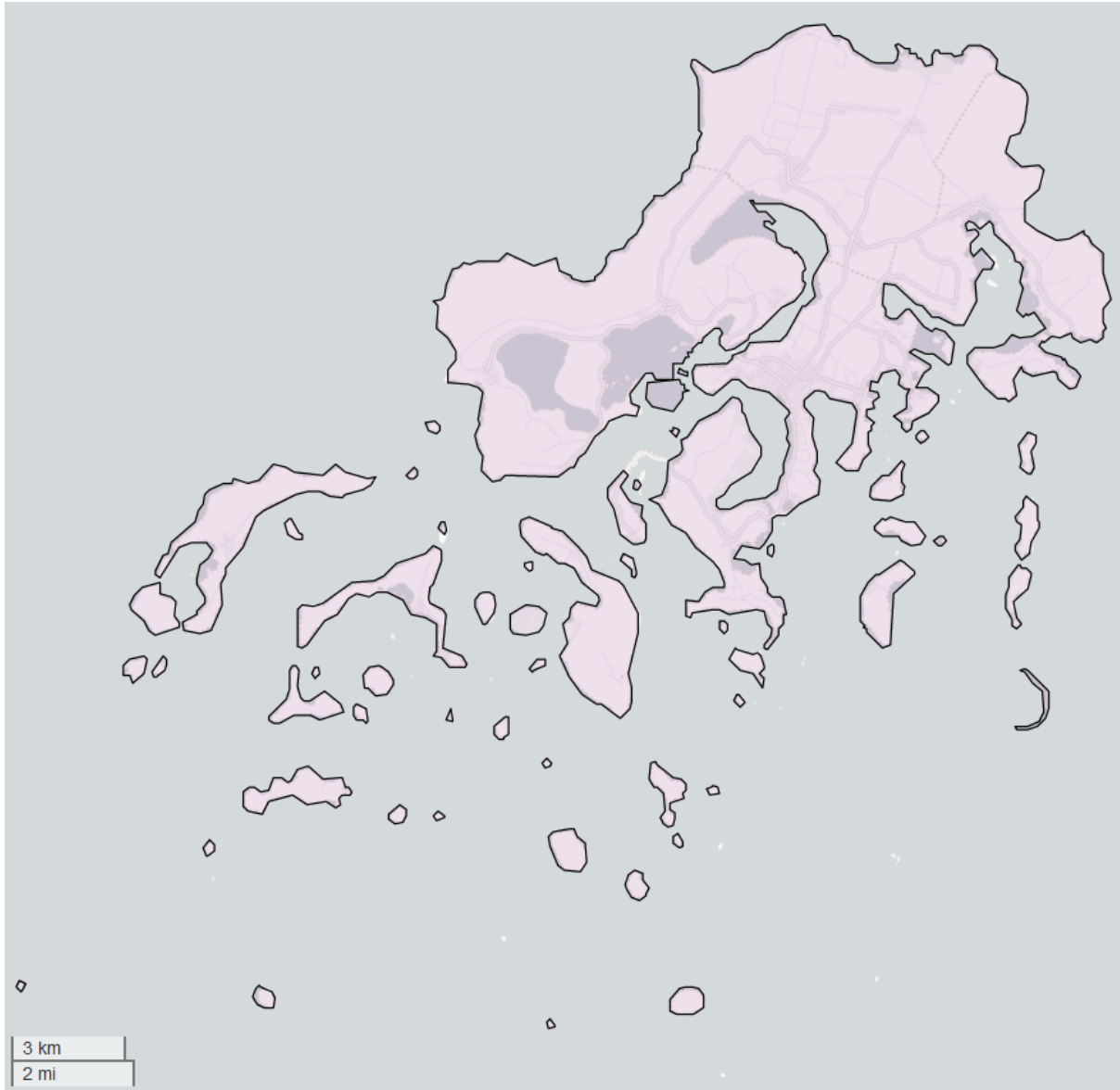
Figure 17: This figure shows the high quality of the Tonga geographic region in the GloNAF dataset.

Biodiversity data, and this data set especially, provide some visualization issues. Heterogeneous data is defined as data that is possibly ambiguous and low quality due to missing values, high data redundancy and untruthfulness (Wang, 2017). Heterogeneity is a known issue with ecological data (Reichman et al., 2011). The GloNAF dataset contains some heterogeneity, as it combines 210 different sources, all which have differing levels of confidence, accuracy, and scale. An example from the GloNAF is the use of the words naturalized and alien. The GLoNAF database standardized their use of

the words naturalized and alien, but some of the data sources they included used the words "established", "exotic", or "introduced". The word choice and definition for what naturalized or alien meant varied between sources, and this ambiguity is noted in the metadata for the GloNAF. Another example is the completeness field. This field ranks the inventory completeness of a taxon list. A taxon list is either very incomplete (under 50% naturalized taxa included), likely incomplete (between 50-90% naturalized taxa included), or likely nearly complete (over 90% taxa included). These scores are noted as being crude and subjective and are given a warning to use them cautiously (Kleunen et al., 2019). It is also important to note that the source area is sometimes different than that of the GloNAF region. For example, a source might be for the entirety of Germany, as opposed to just one of the German states. It is important be transparent and make it clear that uncertainty and ambiguity exists within the dataset when visualizing it.

Auer (2011) describes how the inherent phylogenetic hierarchy of a flora dataset presents a challenge for interfacing with a large dataset. Plant taxonomy categories (family, genus, species, etc.) are not logically queried independently (i.e. one would not want to search for all records based on species name alone, but instead genus and species, after family). Along with the understanding that most users do not know the family of a given plant species, having the user type a family name to start a query is not ideal (Auer et al., 2011). That said, the used dataset consists of 13,393 different taxa and 288 families. This would make for an unwieldy drop down menu, as the user would have to scroll for a long time. An autocomplete search dropdown concept was decided upon, as that would allow the user to type the first few letters of the plant species, then select from a shortened list. This autocomplete dropdown search was noted and set to be implemented in stage four.

Visualizing the pacific islands is a geovisualization challenge in itself. More time would be needed to properly display all 139 islands in a way that would satisfy both the developer and the user. The main difficulties are the small sizes of the islands and the large amount of area in between them. In the GloNAF dataset, the pacific islands extend over 12,000 kilometers. The largest island, New Caledonia, is 19,230 km². All but six islands are under 1,000 km² however. The large distance between these small islands makes for a difficult visualization problem.

To counter this, all the islands were converted to circles except for the four main Hawaiian islands and New Caledonia. Though not ideal, it allowed time for focusing on visualizing the data rather than visualizing the pacific islands themselves. With more time, a visualization showing the island when clicked would be ideal. Though small, many of these islands have large taxa counts; an example being Lana'i, a small 366 km² Hawaiian island, that contains 403 different invasive taxa. As these islands provide a unique insight into biological invasion due to their remote location and low populations, it is important

to make their continent view just as pleasing and useful as the other, easier to represent continents.

4.4   Stage Four

Stage four, the skeleton stage, began the process of arranging the atlas objects into meaningful categories. This stage began by developing the three views: the World View, the Continent View, and the Plant View.

The Plant View is used to visualize the spatial distribution of specific plants. The user is able to search for a plant name at the top of the page and once selected, centroid dots will appear on the regions where the plant is naturalized or alien. This search uses the autocomplete dropdown search menu that was discussed in stage three. The GloNAF dataset consists of 13,939 different taxa and each is included in this view.
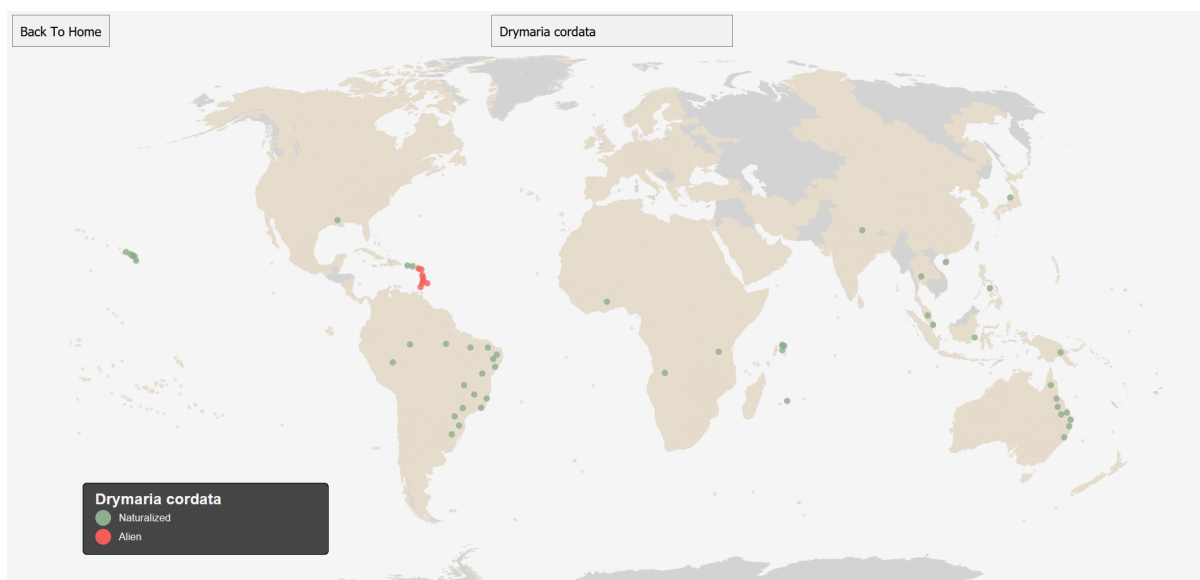
Figure 18:   The Prototype Version of the Plant View

The World View allows the target users to focus solely on global phenomena. To keep the focus on global patterns, the view restricts the user from zooming in or changing the map scale. The user can change map styles on the sidebar panel and can hover or click on map features to retrieve more information on a specific region. The map style for completeness uses a qualitative color scheme which depicts inventory completeness. This is based on the sources for a region. Sources are ranked by their coverage of the area and the confidence level. If the confidence level is not mentioned by the source's author, one is assigned by a member of the GloNAF core team. The map style for tax count per region is a sequential color scheme representing taxa count per square kilometer.

The World View also allows the users to visualize the spatial distribution of plant families. Once a family is selected in the sidebar, a graduated symbol map will appear showing

the amount of families per GloNAF region. Graduated symbol maps have a strength in visualizing quantities, as opposed to densities. Creating the graduated symbol map was completed by calculating the centroid of each GloNAF region. Then, attaching the family count data to the centers. Once a family is selected, the centroids change sizes based on the amount of family in that region.
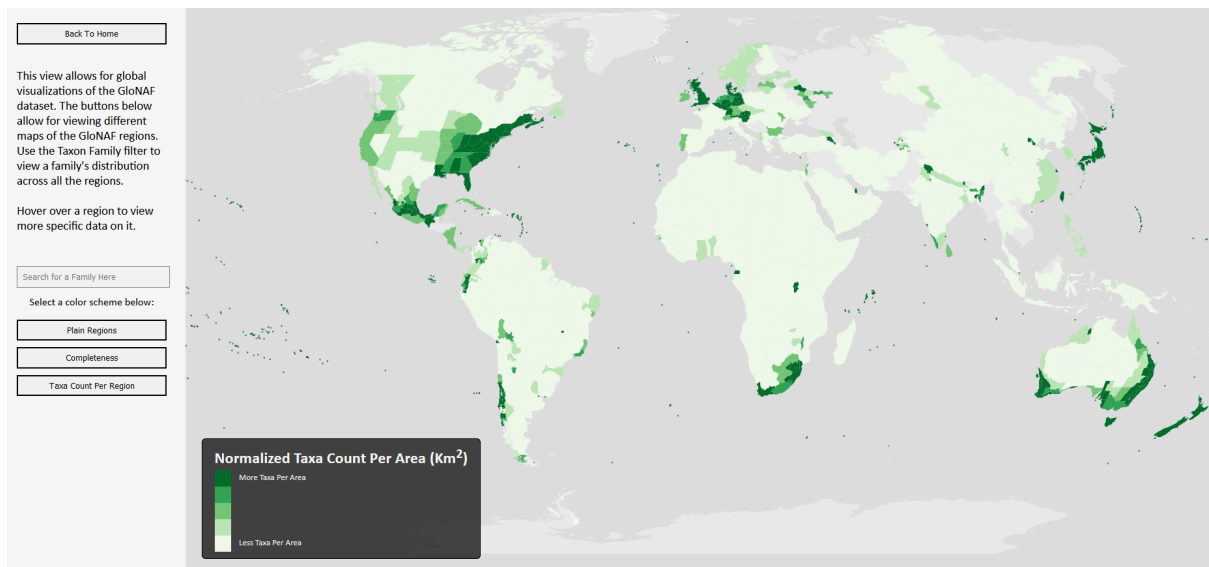
Figure 19: The prototype version of the World View showing the taxa count visualization
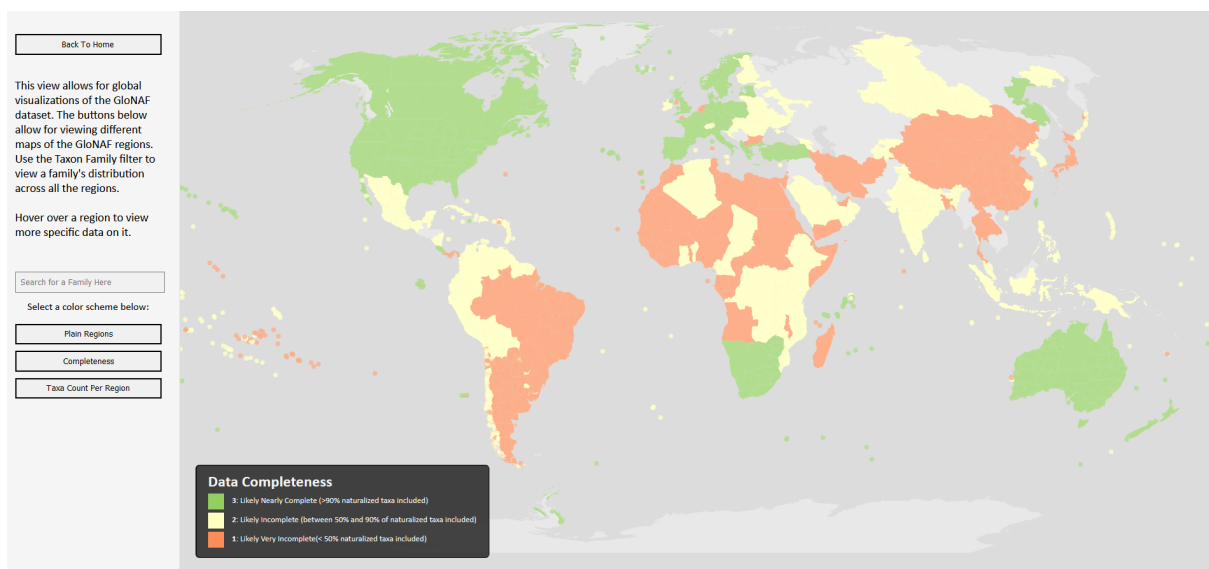
Figure 20: The prototype version of the World View showing the completeness visualization.

The goal of the Continent View is to visualize the same data as the World View, but at a different scale. Inventory completeness, taxa count, and taxa family distribution can be viewed at a continent level. This view begins with a global overview like that of the World View, however, the user is able to click a continent to zoom in to it. Once a continent is clicked, or the corresponding button is clicked, that continent is zoomed upon and the

projection is changed to one that represents the continent in an accurate and visually pleasing way. From there, the user can change visualizations, hover, and click on regions within the continent to access more information. Figure 21 shows the starting view of the Continent View, while Figure 22 shows the zoomed view of the North American continent.
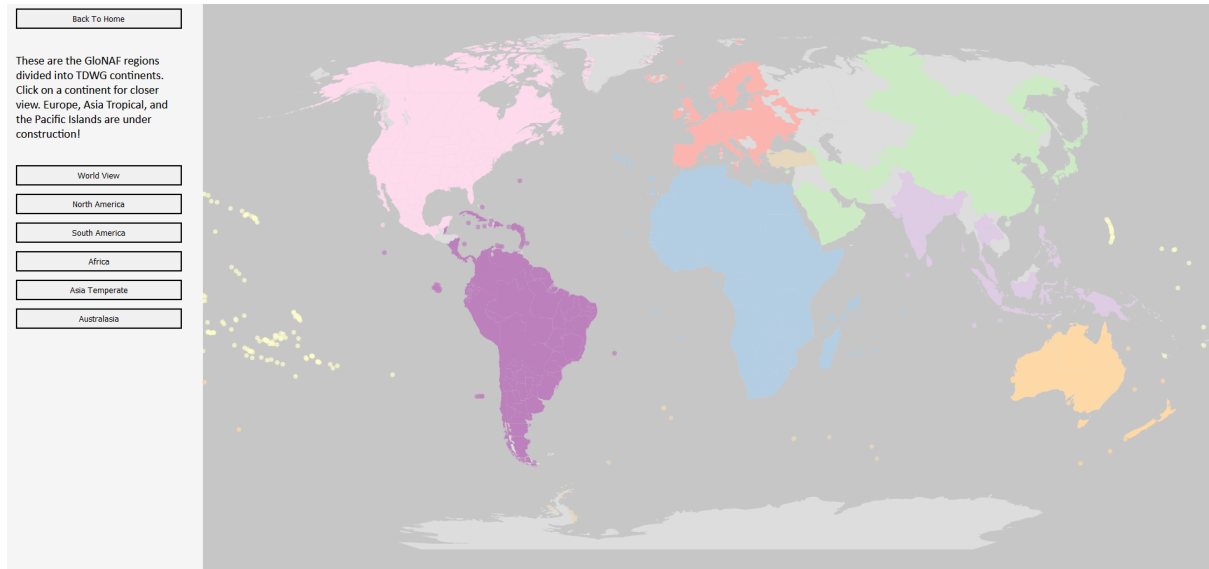
Figure 21: The prototype version of the Continent View.
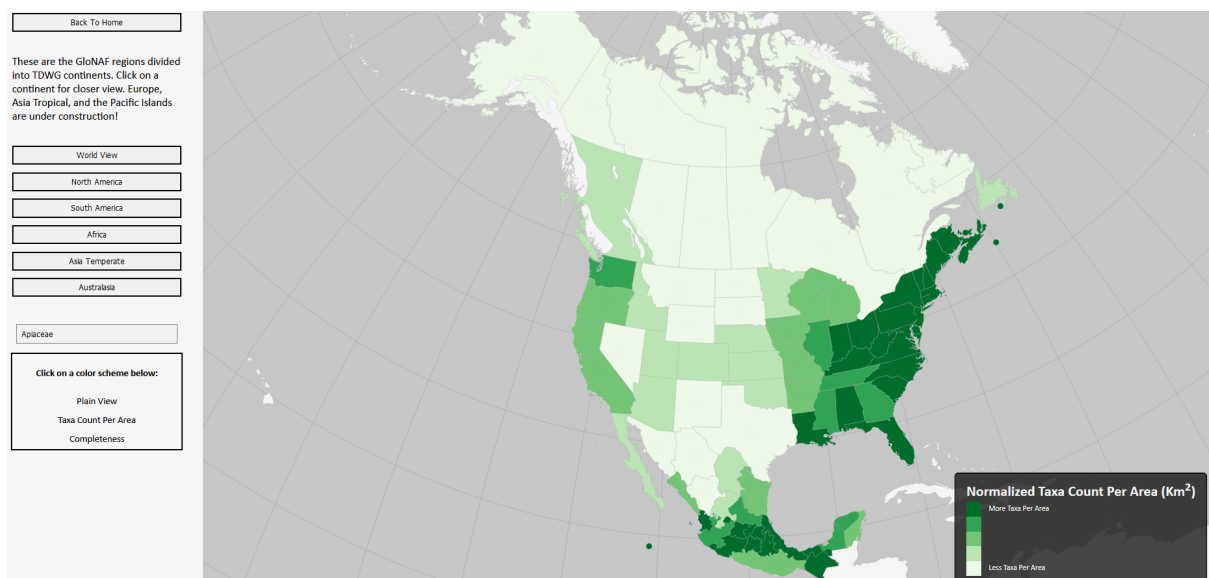
Figure 22: The prototype version of the Continent View showing the North American Continent.

For the Continent View, each continent is projected using a projection that best suits that area. Figure 23 lists the projections used for each continent.

The maps are all accessible via a homepage that lets the user select which view they would like to see. This homepage also provides information on what the interactive is and a link to the source data. Figure 24 shows the homepage.

Continents	Projection Used
North America	Aitoff
South America	Mercator
Europe	Conic Conformal
Australasia	Conic Conformal
Africa	Mercator
Asia Temperate	Robinson
Asia Tropical	Mercator
Pacific Islands	Mercator

Figure 23: Projections used for each continent.

The GloNAF Interactive Atlas

This interactive atlas visualizes the GloNAF (Global Naturalized Alien Flora) dataset. The GloNAF is a living database project about alien plant species. This data compendium includes over 13,900 taxa and covers 1,029 different regions, including 381 islands (as of 8/10/2020). It is based on 210 different sources.

The GloNAF dataset and published paper can be found here.

Click on a map below to view it

World View
Get a Global Overview of the GloNAF Dataset

Continent View
Explore the GloNAF Dataset by Continent

Plant View
View Where Specific Plants are Native or Invasive

Figure 24: Atlas Home Page

Projection is an important cartographic concept, and therefore important for atlases. One of the main development choices for using D3 was the ability to change the projection from the default web Mercator that is used for most web mapping applications. For the global views in the World View, Continent View, and Plant View the Robinson projection is used. The Robinson projection's strength is balancing geographic accuracy with aesthetics. The Robinson projection was developed in 1974 by Arthur Robinson and is a compromise projection. It does not eliminate any type of distortion, but keeps the levels of all types of distortion relatively low over most of the map (Dean, n.d.). It is an incredibly popular

projection and it is the most commonly used projection in world atlases (Šavrič et al., 2015).

4.4.1 User Test Results

The user test was completed by ten members of the GloNAF core team. It was also completed by nine other, randomly chosen users to provide outside feedback. Though the atlas is intended just for the GloNAF team, the team has potential to change or add new members. Due to the diverse nature of geovisualization interface users and their tasks, it is valuable to gather feedback from other users (MacEachren & Kraak, 2001). The results of the user test varied, but overall showed positive reactions of the interactive atlas at this point. Many suggestions were given as well, which would help guide the updates for the surface stage.

The GloNAF team members responses were analyzed first. The utility questions showed promising results that the interface was successful in usefulness. The first question "How Many Taxa are in Japan?" was answered correctly by all but one respondent. The next question, "What is the Completeness of California?" was answered correctly by all respondents. The third utility question, "For the Solanaceae family, can you name a region with more than 50 members?" provided some difficulty for the users; only three answered it correctly. This question involved using the search functionality, instead of the style buttons. This signifies that this functionality will need to be updated.

The next two questions intended to test the utility of the Plant View. The questions specifically left out that the Plant View was needed in order to answer questions five and six. This was to test if the users were able to locate and understand what the Plant View did. The user was required to name a region where the taxa Solanum Melongena is naturalized and where it is alien to. All users were able to successfully determine a region where this plant is naturalized, and all but one were successful in locating a region where it is alien to.

Question seven was correctly answered by all GloNAF respondents. Question eight was correctly answered by all but one.

The next questions were meant to test the usability. They start with question nine, which asks the user to judge how difficult it was for them to answer the previous questions. All but two marked "Very Easy", while the other two marked "Easy." These responses indicate that the atlas was useful in answering questions regarding the dataset. Question

ten had similar positive response. All marked it as "Very Pleasing" except for two, who marked it as just "Pleasing".

Questions eleven, twelve, and thirteen relate to the different views. The questions were designed to see if one view in particular was most useful to the user or if one view was the more enjoyable to use. Question eleven asked which view was easiest to use, and the responses are varied. World View received the most votes, but Continent View and Plant View received just one and two less votes that World View respectively. In the comments section, one GloNAF team member mentioned how they found all views to have equal ease of use, but that was not an option on the user test. The responses to question twelve show that most users found the World View to be the most visually pleasing. Continent View came in second place. Plant View received no votes in this category. Question thirteen had most users select "Even Mix of all three" and two users selecting "World View." The responses to these questions show that the World View is favored slightly, but not by much.

Questions fourteen, fifteen, and sixteen focused on learnability. Learnability, how quickly users understand the interface without prior use, is an important measure of usability. It is especially important in the context of an atlas; the user, who is most likely not a GIS or cartographic expert, should not need to spend time learning the interface in order to access it. Accessibility is one of the key components of an atlas, and focusing on an interface that is easy to learn can improve accessibility to data and the overall atlas experience.

All views, except Continent View, received only votes for "Very Easy" and "Easy". Continent View received one vote for very difficult to learn. Overall though, most GloNAF users found that they were able to learn the interface easily.

The final questions asked for comments regarding color schemes, views, or visualization. Many had issues with some surface stage concepts, such as new tabs opening on each view click. Other web cartography design issues were discovered, such as overlapping legends when the view was switched. Color scheme issues were brought up as well, which will be further addressed in the surface stage.

4.5   Stage Five

Stage five involved finalizing the visual layout by bringing everything together. It mostly involved user experience decisions and surface level functions such as icons, buttons, and hyperlinks. Data content symbology and color choice were finalized during this stage.

Feedback from the user test uncovered some usability issues regarding the color choices.

For the Plant View, the colors red and green were used in the prototype to signify alien taxa versus naturalized taxa. GloNAF team members noted that this color scheme might cause some misperception by viewing one option and as bad and one as good. The colors were changed to teal and purple using Colorbrewer, a well-established and popular cartographic palette generator (Harrower & Brewer, 2003). Teal and purple were chosen due to their lack of positive or negative associations. Legend usability issues were discovered during the user test. Overlaps were occurring when the views were switched. Also, depending on the continent, the legend was overlapping parts of the visualization. This was remedied by having the legend move based on which continent is being viewed.

Along with the color scheme, user feedback shaped a redesign of the symbology of the Plant View. Suggestions via the user test noted that some users saw the point data resembling occurrence data instead of just the centroid of the polygon. Occurrence data can be defined as geo-referenced locations where a species was found, which is not what the GloNAF data is showing. In order to remedy this, the region was highlighted instead of just the centroid.
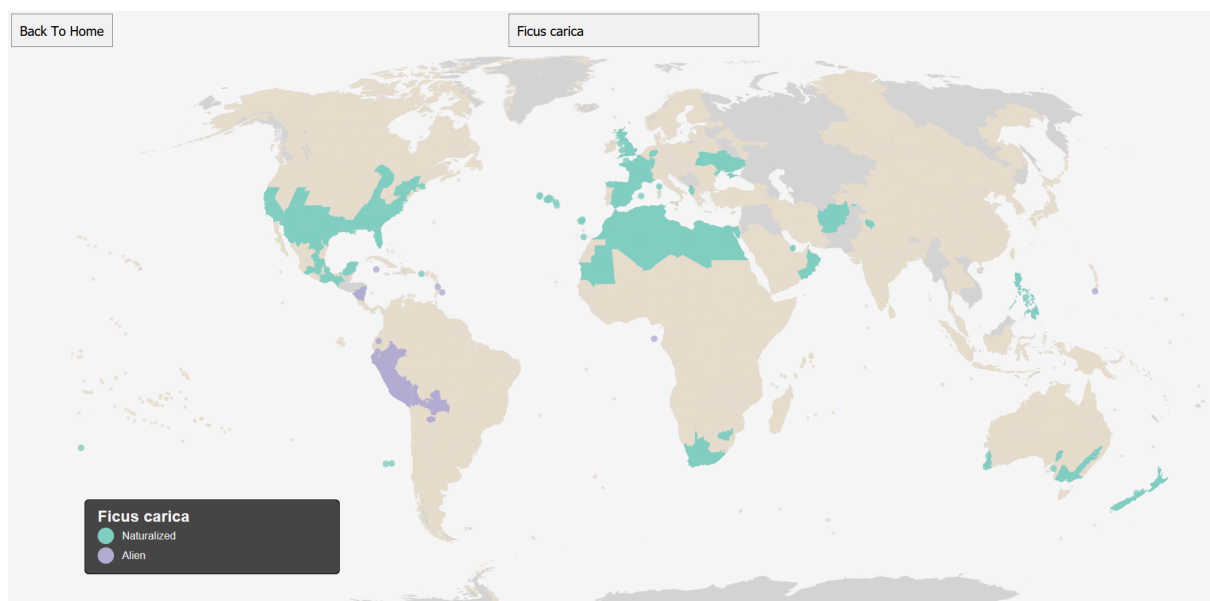
Figure 25: The Updated Plant View with a new color scheme and regions highlighted instead of centroids.

For the Continent View, each continent was assigned a different color. This design choice was made to show which areas fall under which continents. For example, the border between Asia temperate and Asia tropical or which continents specific islands are considered a part of. Continents were decided based on their TDWG level one ranking. In the GloNAF dataset, the country Turkey is listed as its own continent. For visualization purposes, Turkey was added to Asia temperate, where it is classified in the original TDWG data source. The different color choices were again picked from Colorbrewer. Once a

continent is clicked, or the corresponding button is clicked, that continent is zoomed upon and the projection is changed to one that represents that continent in an accurate and visually pleasing way.

5   Conclusions & Discussions

In regards to the first research objective, an interactive atlas was successfully created for the GloNAF dataset. It achieved in taking feedback from the target users and creating an atlas that, from their input, successfully visualized aspects of the dataset. The framework derived from the methods and tested here shows promising results, as the users gave positive feedback to interactive atlas created from its use. The framework provides multiple methods to achieve interface success at each stage of the interactive atlas development process. That said, some improvements could be made. The questions asked during stage one could have been more refined to garner more useful information from the GloNAF team. Specific examples of visualization in the question might have skewed their answers and instead of coming up with their own, they defaulted to the examples given. Examples were provided to help guide the target groups' thinking, as it was possible that the users might not have known what they wanted when first contacted (Roth, Ross, & MacEachren, 2015). That said, any abstract or difficult request could have been discussed or translated into something more tangible in stage two.

Iteration is an important concept for this framework and for the UCD in general. The back and forth process between the user and the developer is vital to success. If more time was available, iterating through the five steps more than once would have provided more user feedback and therefore more updates and usability critiques. In general, gathering more user feedback can always be beneficial.

In regards to the third research question, a minimum standard or requirement of necessary functionalities appears to be difficult to define for all interactive atlases. The competitive analysis and intensive research into the field showed diverse results regarding interaction types. Though all atlases that were compared in the competitive analysis had the ability to zoom and request specific details about a map feature of interest, this does not seem like enough evidence to say that all interactive atlases need those specific interaction functionalities. The use case and application for atlases is vast, and the interaction needs can vary based on the atlas map content and the target user group.

One reason for the diverse results regarding interaction types could be the wide array of mapping libraries currently available. In the eight atlases compared, seven different mapping technologies were utilized. Each mapping library has certain functionalities built in, and it is plausible to assume that atlas developers would try and utilize the built-in

interaction functionalities before adding on extra ones.

The decision to use D3 for the atlas instead of a client-side library designed solely for web mapping was a difficult one. It was made for an important reason: D3 allows for better cartographic representation. The ability to handle high amounts of spatial data efficiently from multiple data sources (CSV, JSON, GeoJSON) and utilize multiple map projections made D3 stand above the other choices. As mentioned above though, it is possible that usability was hindered due to the choice of using D3. Though not as cartographic, Leaflet, Mapbox, and OpenLayers provide usability functions, such as panning, zooming, and the ability to use tile maps, with minimal coding. Because of this, one could argue that the tile-based technologies allow the developer to enable a higher level of exploration with less code.

Usability testing regarding the technology stack would have been a useful step for developing the GloNAF interactive atlas. A suggestion for future work would be developing an atlas with one of other above mentioned tile-based JavaScript libraries and comparing both the utility and usability to the D3 one from this thesis. A tile-based mapping library would allow for the addition of data served in tiles from Web Map Services and Web Feature Services. These are two very common sources for geospatial data that many data providers use, and adding more relevant data to the atlas would most likely add value. It is also possible that interaction and loading times could be decreased if a tile-based technology was used.

Regarding technology, arguments could be made either way for the use of a database. The traditional interactive atlas system uses server-side technologies, which usually means using a database such as PostgreSQL. For spatial data, an additional plugin, PostGIS, is often used. PostgreSQL has over thirty years of active development and it has a strong reputation for reliability, feature robustness, and performance. Combined with PostGIS, this database supports geographic objects and understands projections, transformations, and coordinate systems. PostgreSQL and PostGIS also allow for different data types; one can access their data via tiles or GeoJSON, making it a very flexible tool.

Storing data in a database is also easier to maintain and manage, as the developer does not have to manage different data files. Updating and editing data can be completed in the database itself, and files do not need to be changed. By using GeoJSON's, each time the data was updated, a new GeoJSON had to be created. This does pose possible issues for future users, as each time the dataset is updated, the files will have to be updated individually.

That said, by not using server-side technologies, the interactive atlas can be hosted on GitHub. GitHub is a well known version control hosting platform for software development.

By hosting the code on GitHub, a URL is able to be created for free and the atlas can be accessed by anyone with a computer. Being able to access the atlas via a URL is a noticeably easier way to access the atlas than having to download the code and run a local server to access it. Another benefit is that the development code for the atlas is available online to be viewed and accessed by anyone. This makes it easier to collaborate and for further work to be completed on the atlas after the thesis.

The inconclusive result of the third research objective leads to some interesting future work considerations. The competitive analysis completed for this thesis was useful, but an expanded competitive analysis could provide even more useful results regarding representation and interaction methods. The competitive analysis used in this thesis did not take into consideration any other aspects of the atlas besides the representation and interaction methods used. For example, an atlas in the study might have included all interaction types, but the usability of the atlas might have been subpar. An expanded study could fully compare interactive atlases to determine if specific interactive methods yielded higher usability results than others.

5.1 Future Work

Future work could incorporate other data sets into this atlas. The developmental framework created can be used for further data additions to the atlas. Visualizing time data is a data visualization often seen in atlases. Due to the nature of the data and scope of this thesis, time data visualization for biological invasion could be a future work consideration. Visualizing biological invasion, that is, visualizing the spread of a specific taxa from its origin to other regions would be interesting and useful for GloNAF research and could be seen as a next step in the interactive GloNAF atlas. Flow maps would be an ideal visualization of biological invasion. Flow maps visualize movement from one location to another, and could visually demonstrate the invasion process.

Data is available that shows the naturalized species accumulation for the nine TDWG continents. Data is also available that could visualize the flow of naturalized species among continents (van Kleunen et al., 2015). Socio-economic factors, such as land use types, transportation networks, and Gross Domestic Product, are also relevant for biological invasion and could be added in as well. Population density is a large factor as well, and datasets from the NASA Socioeconomic Data and Applications Center or the Wittgenstein Centre would be useful in visualizing this.

More atlas features could be added as well. A comparison feature, where the user could view two different continents at the same time would be a useful atlas feature. A region lookup, where a user types in a region to find more information about it, would be useful,

especially if a user could not specifically locate a region spatially. This would be useful for small islands and region especially.

Research into the utility-usability trade-off with respect to atlases is a topic that could lead to answers to the third research question. Is there a way for a framework to determine what the utility threshold of an atlas can be? Usability, as described in the theory section above, is paramount for a thesis. A target user group with a high knowledge level of technology and GIS tools could handle an atlas with low usability but high utility. That would be an outlier case though. Atlases foremost should be a cartographic and usable information system that can be used and enjoyed by a wide array of users. An argument could be made that usability is more important than utility in an atlas, but determining by how much or coming up with a method to test this would be interesting future research.

Accompanying the further studies in utility-usability trade-off, AIS user interfaces is a field where research is lacking. As cartographic interaction becomes even more advanced due to the inevitable development of front end web technologies, usability testing on advanced GIS interactions will become increasingly important. The line between a GIS and AIS will become more blurry, as both high quality visualization and high level spatial interaction will be available in one system. Specific interactivity questions will need to be answered, such as if cartographic interaction differs in the context of map mashups, one off web maps, or mapping systems (Roth, 2013). Further definitions and distinctions will need to be made.

References

Aditya, T., & Kraak, M.-J. (2005). The atlas as a portal for data discovery in the GDI : prospects and development.

Agafonkin, V. (2010). *Leaflet - a JavaScript library for interactive maps.* Retrieved 2020-04-24, from https://leafletjs.com/

Alonso, P. G. (1968, December). The First Atlases. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *5*(2), 108–121. Retrieved 2020-08-28, from https://utpjournals.press/doi/10.3138/W635-647V-3684-11V4

Atlas. (2020). Retrieved 2020-10-12, from https://www.merriam-webster.com/dictionary/ atlas

Auer, T., MacEachren, A. M., McCabe, C., Pezanowski, S., & Stryker, M. (2011, March). HerbariaViz: A web-based client–server interface for mapping and exploring flora observation data. *Ecological Informatics*, *6*(2), 93–110. Retrieved 2020-04-19, from https://linkinghub.elsevier.com/retrieve/pii/S1574954110000968

Battersby, S. E., Finn, M. P., Usery, E. L., & Yamamoto, K. H. (2014, June). Implications of Web Mercator and Its Use in Online Mapping. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *49*(2), 85–101. Retrieved 2020-05-13, from https://utpjournals.press/doi/10.3138/carto.49.2.2313

Black, M., & Cartwright, W. (2005). Web Cartography & Web-enabled Geographic Information Systems (GIS) New Possibilities, New Challenges. Melbourne, Australia.

Borchert, A. (1999). Multimedia Atlas Concepts. In W. Cartwright, M. P. Peterson, & G. Gartner (Eds.), *Multimedia Cartography* (pp. 75–86). Berlin, Heidelberg: Springer. Retrieved 2020-09-29, from https://doi.org/10.1007/978-3-662-03784-3_7

Bostock, M., Ogievetsky, V., & Heer, J. (2011, December). D^3 Data-Driven Documents. *IEEE Transactions on Visualization and Computer Graphics*, *17*(12), 2301–2309. Retrieved 2020-04-19, from http://ieeexplore.ieee.org/document/6064996/

Brummitt, R. (2001). *World Geographical Scheme for Recording Plant Distributions, Edition 2. Biodiversity Information Standards (TDWG).* Retrieved 2020-09-03, from http://www.tdwg.org/standards/109

Buckley, A. (2003, January). Atlas Mapping in the 21st Century. *Cartography and Geographic Information Science*, *30*(2), 149–158. Retrieved 2020-08-10, from http:// www.tandfonline.com/doi/abs/10.1559/152304003100011117

Buckley, A., Meacham, J., & Steiner, E. (2003). Creating a State Atlas as an Integrated Set of Resources: Book, CD-ROM and Website. In *Proceedings of the 21st International Cartographic Conference (ICC)* (p. 15). Durban, South Africa.

Butler, H., Daly, M., Doyle, A., Gillies, S., Hagen, S., & Schaub, T. (2016, August). *The GeoJSON Format* (Tech. Rep. No. RFC7946). RFC Editor. Retrieved 2020-09-22,

from https://www.rfc-editor.org/info/rfc7946

Bär, H. R., & Sieber, R. (1999). Towards High Standard Interactive Atlases The GIS and multimedia cartography approach. In *Proceedings of the 19th International Cartographic Conference* (pp. 235–241). Ottawa.

Cartwright, W., Crampton, J., Gartner, G., Miller, S., Mitchell, K., Siekierska, E., & Wood, J. (2001, January). Geospatial Information Visualization User Interface Issues. *Cartography and Geographic Information Science*, *28*(1), 45–60. Retrieved 2020-07-27, from http://www.tandfonline.com/doi/abs/10.1559/152304001782173961

Cartwright, W., Peterson, M. P., & Gartner, G. (1999). *Multimedia Cartography.* Berlin, Heidelberg: Springer Berlin Heidelberg. Retrieved 2020-09-29, from https://doi.org/10.1007/978-3-662-03784-3 (OCLC: 851371719)

Cartwright, W., Peterson, M. P., & Gartner, G. (Eds.). (2007). *Multimedia cartography* (2nd ed.). Berlin ; New York: Springer.

Clarke, K. C. (1986, January). Advances in Geographic Information Systems. *Computers, Environment and Urban Systems*, *10*(3), 175–184. Retrieved 2020-09-15, from http://www.sciencedirect.com/science/article/pii/0198971586900062

Dawson, W., Moser, D., van Kleunen, M., Kreft, H., Pergl, J., Pyšek, P., … Essl, F. (2017, July). Global hotspots and correlates of alien species richness across taxonomic groups. *Nature Ecology & Evolution*, *1*(7), 0186. Retrieved 2020-03-30, from http://www.nature.com/articles/s41559-017-0186

Dean, D. (n.d.). *The Robinson Projection – Robinson Map Library.* Retrieved 2020-09-08, from https://geography.wisc.edu/maplibrary/the-robinson-projection/

Dillman, D. A., Smyth, J. D., & Christian, L. M. (2014). *Internet, phone, mail, and mixed-mode surveys: the tailored design method* (4th edition ed.). Hoboken: Wiley.

Donohue, R. G. (2014). *Web Cartography with Web Standards: Teaching, Learning, and Using Open Source Web Mapping Technologies* (Unpublished doctoral dissertation). University of Wisconsin-Madison.

Donohue, R. G., Sack, C. M., & Roth, R. E. (2014, October). Time Series Proportional Symbol Maps with Leaflet and jQuery. *Cartographic Perspectives*(76), 43–66. Retrieved 2020-08-29, from https://cartographicperspectives.org/index.php/journal/article/view/cp76-donohue-et-al

Essl, F., Dawson, W., Kreft, H., Pergl, J., Pyšek, P., Van Kleunen, M., … Winter, M. (2019, September). Drivers of the relative richness of naturalized and invasive plant species on Earth. *AoB PLANTS*, *11*(5), plz051. Retrieved 2020-03-30, from https://academic.oup.com/aobpla/article/doi/10.1093/aobpla/plz051/5559683

Farkas, G. (2017, July). Applicability of open-source web mapping libraries for building massive Web GIS clients. *Journal of Geographical Systems*, *19*(3), 273–295. Retrieved 2020-04-13, from http://link.springer.com/10.1007/s10109-017-0248-z

Garrett, J. J. (2002). *The elements of user experience: user-centered design for the Web and beyond* (2nd ed ed.). Berkeley, CA: New Riders. (OCLC: ocn503049598)

Gartner, G., Kriz, K., Spanring, C., & Pucher, A. (2005). The Concept of "Restrictive Flexibility" in the "ÖROK Atlas Online". , 6.

Grinstein, G., Kobsa, A., Plaisant, C., & Stasko, J. (2003, October). Which comes first, usability or utility? In *IEEE Visualization, 2003. VIS 2003.* (pp. 605–606).

Haklay, M., & Zafiri, A. (2008, May). Usability Engineering for GIS: Learning from a Screenshot. *The Cartographic Journal*, *45*(2), 87–97. Retrieved 2020-07-13, from http://www.tandfonline.com/doi/full/10.1179/174327708X305085

Harrower, M., & Brewer, C. A. (2003, June). ColorBrewer.org: An Online Tool for Selecting Colour Schemes for Maps. *The Cartographic Journal*, *40*(1), 27–37. Retrieved 2020-10-03, from https://www.tandfonline.com/doi/abs/10.1179/000870403235002042 (Publisher: Taylor & Francis _eprint: https://www.tandfonline.com/doi/pdf/10.1179/000870403235002042)

Hurni, L., Bär, H.-R., & Sieber, R. (1999). The Atlas of Switzerland as an Interactive Multimedia Atlas Information System. In W. Cartwright, M. P. Peterson, & G. Gartner (Eds.), *Multimedia Cartography* (pp. 99–112). Berlin, Heidelberg: Springer. Retrieved 2020-09-29, from https://doi.org/10.1007/978-3-662-03784-3_9

Janicki, J., Narula, N., Ziegler, M., Guénard, B., & Economo, E. P. (2016, March). Visualizing and interacting with large-volume biodiversity data using client–server web-mapping applications: The design and implementation of antmaps.org. *Ecological Informatics*, *32*, 185–193. Retrieved 2020-04-13, from https://linkinghub.elsevier.com/retrieve/pii/S1574954116300097

Jetz, W., McPherson, J. M., & Guralnick, R. P. (2012, March). Integrating biodiversity distribution knowledge: toward a global map of life. *Trends in Ecology & Evolution*, *27*(3), 151–159. Retrieved 2020-10-01, from https://linkinghub.elsevier.com/retrieve/pii/S0169534711002679

Keates, J. S. (1989). *Cartographic Design and Production*. Longman Scientific & Technical. (Google-Books-ID: Q0rO2BYAs2kC)

Kessler, F. (2000, December). Focus Groups as a Means of Qualitatively Assessing the U-Boat Narrative. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *37*(4), 33–60. Retrieved 2020-10-04, from https://utpjournals.press/doi/10.3138/C631-1LM4-14J3-1674

Kleunen, M., Pyšek, P., Dawson, W., Essl, F., Kreft, H., Pergl, J., . . . Winter, M. (2019, January). The Global Naturalized Alien Flora (GloNAF) database. *Ecology*, *100*(1). Retrieved 2020-03-30, from https://onlinelibrary.wiley.com/doi/abs/10.1002/ecy.2542

Kraak, M.-J., & Brown, A. (2005). *Web Cartography*. Hoboken: CRC Press. (OCLC:

911177607)

Kraak, M.-J., & Ormeling, F. (2010). *Cartography: visualization of geospatial data* (3rd ed.). Harlow ; New York: Prentice Hall. (OCLC: ocn477062041)

Lechthaler, M., Spanring, C., & Katzlberger, G. (2006). Cartographic Information System "ÖROK Atlas Online" – AIS Austria as a Communication Portal of Austrian Basic Geo-Data. , 18.

Li, S., Dragićević, S., & Veenendaal, B. (Eds.). (2011). *Advances in web-based GIS, mapping services and applications*. Boca Raton, Fla: CRC Press/Balkema.

Lloyd, D. (2009). *Evaluating human-centered approaches for geovisualization* (Unpublished doctoral dissertation). City University London, London.

MacEachren, A. M., Crawford, S., Akella, M., & Lengerich, G. (2008, November). Design and Implementation of a Model, Web-based, GIS-Enabled Cancer Atlas. *The Cartographic Journal*, *45*(4), 246–260. Retrieved 2020-04-19, from http://www.tandfonline.com/doi/full/10.1179/174327708X347755

MacEachren, A. M., & Kraak, M.-J. (2001, January). Research Challenges in Geovisualization. *Cartography and Geographic Information Science*, *28*(1), 3–12. Retrieved 2020-08-26, from http://www.tandfonline.com/doi/abs/10.1559/152304001782173970

Machwitz, M., Hass, E., Junk, J., Udelhoven, T., & Schlerf, M. (2019, June). CropGIS – A web application for the spatial and temporal visualization of past, present and future crop biomass development. *Computers and Electronics in Agriculture*, *161*, 185–193. Retrieved 2020-04-19, from https://linkinghub.elsevier.com/retrieve/pii/S0168169917306099

Monmonier, M. S. (1981, October). Trends in Atlas Development. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *18*(2), 187–213. Retrieved 2020-07-19, from https://utpjournals.press/doi/10.3138/1572-LG43-R75T-5455

Moreno-Sánchez, R., Malczewski, J., & Bojorquez-Tapia, L. A. (1996, June). Design and development strategy for multi-media GIS to support environmental negotiation, administration, and monitoring at the regional level. *Transactions in GIS*, *1*(3), 161–175. Retrieved 2020-10-06, from http://doi.wiley.com/10.1111/j.1467-9671.1996.tb00042.x

Nielsen, J. (1992). *The Usability Engineering Life Cycle.*

Ormeling, F. (1995). Atlas Information Systems. In *Atlas Information Systems* (p. 7). Barcelona.

Padilla-Ruiz, M., Church, I., & Stefanakis, E. (2018). Competitive Analysis of Current Ocean Web-Mapping Applications. *International Hydrographic Review*, 18.

Padilla-Ruiz, M., Stefanakis, E., & Church, I. (2019, November). Development of a User-Centred Web-Mapping Application for Ocean Modellers. *Marine Geodesy*,

42(6), 507–534. Retrieved 2020-08-24, from https://www.tandfonline.com/doi/full/10.1080/01490419.2019.1666758

Panchaud, N., Iosifescu-Enescu, I., Eichenberger, R., & Hurni, L. (2013). Service-Driven 3D Atlas Cartography. In (p. 15). Dresden, Germany.

Peterson, M. P. (1995). *Interactive and animated cartography.* Englewood Cliffs, N.J: Prentice Hall.

Peterson, M. P. (Ed.). (2008). *International perspectives on maps and the Internet.* Berlin ; New York: Springer.

Pulsifer, P. L., Parush, A., Lindgaard, G., & Fraser Taylor, D. (2005). Chapter 20 The development of the cybercartographic atlas of antarctica. In *Modern Cartography Series* (Vol. 4, pp. 461–490). Elsevier. Retrieved 2020-07-12, from https://linkinghub.elsevier.com/retrieve/pii/S1363081405800231

Ramos, C. d. S., & Cartwright, W. (2006). Atlases from Paper to Digital Medium. In E. Stefanakis, M. P. Peterson, C. Armenakis, & V. Delis (Eds.), *Geographic Hypermedia: Concepts and Systems* (pp. 97–119). Berlin, Heidelberg: Springer. Retrieved 2020-09-25, from https://doi.org/10.1007/978-3-540-34238-0_6

Reichman, O. J., Jones, M. B., & Schildhauer, M. P. (2011, February). Challenges and Opportunities of Open Data in Ecology. *Science*, *331*(6018), 703–705. Retrieved 2020-10-07, from https://www.sciencemag.org/lookup/doi/10.1126/science.1197962

Robinson, A. C., Chen, J., Lengerich, E. J., Meyer, H. G., & MacEachren, A. M. (2005, January). Combining Usability Techniques to Design Geovisualization Tools for Epidemiology. *Cartography and Geographic Information Science*, *32*(4), 243–255. Retrieved 2020-08-30, from http://www.tandfonline.com/doi/abs/10.1559/152304005775194700

Robinson, A. C., MacEachren, A. M., & Roth, R. E. (2011, September). Designing a web-based learning portal for geographic visualization and analysis in public health. *Health Informatics Journal*, *17*(3), 191–208. Retrieved 2020-08-30, from http://journals.sagepub.com/doi/10.1177/1460458211409718

Roth, R. E. (2013, June). Interactive maps: What we know and what we need to know. *Journal of Spatial Information Science*(6), 59–115. Retrieved 2020-08-13, from http://www.josis.org/index.php/josis/article/view/105

Roth, R. E. (2015, June). Interactivity and Cartography: A Contemporary Perspective on User Interface and User Experience Design from Geospatial Professionals. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *50*(2), 94–115. Retrieved 2020-05-15, from https://utpjournals.press/doi/10.3138/cart.50.2.2427

Roth, R. E., Donohue, R. G., Sack, C. M., Wallace, T. R., & Buckingham, T. M. A. (2013, August). A Process for Assessing Emergent Web Mapping Technologies. In

Proceedings of the 26th International Cartographic Conference (p. 15). Dresden, Germany.

Roth, R. E., Donohue, R. G., Sack, C. M., Wallace, T. R., & Buckingham, T. M. A. (2014, December). A Process for Keeping Pace with Evolving Web Mapping Technologies. *Cartographic Perspectives*(78), 25–52. Retrieved 2020-08-23, from https://cartographicperspectives.org/index.php/journal/article/view/cp78-roth-et-al

Roth, R. E., & Harrower, M. (2008, June). Addressing Map Interface Usability: Learning from the Lakeshore Nature Preserve Interactive Map. *Cartographic Perspectives*(60), 46–66. Retrieved 2020-06-28, from https://cartographicperspectives.org/index.php/journal/article/view/cp60-roth-harrower

Roth, R. E., Hart, D., Mead, R., & Quinn, C. (2017, July). Wireframing for interactive & web-based geographic visualization: designing the NOAA Lake Level Viewer. *Cartography and Geographic Information Science*, *44*(4), 338–357. Retrieved 2020-09-10, from https://www.tandfonline.com/doi/full/10.1080/15230406.2016.1171166

Roth, R. E., Quinn, C., & Hart, D. (2015). The Competitive Analysis Method for Evaluating Water Level Visualization Tools. In J. Brus, A. Vondrakova, & V. Vozenilek (Eds.), *Modern Trends in Cartography* (pp. 241–256). Cham: Springer International Publishing. Retrieved 2020-08-23, from http://link.springer.com/10.1007/978-3-319-07926-4_19 (Series Title: Lecture Notes in Geoinformation and Cartography)

Roth, R. E., Ross, K., & MacEachren, A. (2015, February). User-Centered Design for Interactive Maps: A Case Study in Crime Analysis. *ISPRS International Journal of Geo-Information*, *4*(1), 262–301. Retrieved 2020-05-15, from http://www.mdpi.com/2220-9964/4/1/262

Sack, C. M., Donohue, R. G., & Roth, R. E. (2015, February). Interactive and Multivariate Choropleth Maps with D3. *Cartographic Perspectives*(78), 57–76. Retrieved 2020-09-30, from https://cartographicperspectives.org/index.php/journal/article/view/cp78-sack-et-al

Schneider, B. (1999). Integration of analytical GIS-functions in Multimedia Atlas Information Systems. In *Proceedings of the 19th International Cartographic Conference* (pp. 243–250). Ottawa: ICC.

Schneider, B. (2001). GIS Functionality in Multimedia Atlases: Spatial Analysis for Everyone. In *Proceedings of the 20th International Cartographic Conference* (pp. 829–840). Beijing.

Schnürer, R., Sieber, R., & Çöltekin, A. (2015). The Next Generation of Atlas User Interfaces: A User Study with "Digital Natives". In J. Brus, A. Vondrakova, & V. Vozenilek (Eds.), *Modern Trends in Cartography: Selected Papers of CARTOCON 2014* (pp. 23–36). Cham: Springer International Publishing. Retrieved 2020-09-25,

from https://doi.org/10.1007/978-3-319-07926-4_3

Shneiderman, B. (1996). The eyes have it: a task by data type taxonomy for information visualizations. In *Proceedings 1996 IEEE Symposium on Visual Languages* (pp. 336–343). Boulder, CO, USA: IEEE Comput. Soc. Press. Retrieved 2020-10-11, from http://ieeexplore.ieee.org/document/545307/

Sieber, R., Geisthövel, R., & Hurni, L. (2009). Atlas of Switzerland 3 A Decade of Exploring Interactive Atlas Cartography. , 14.

Sieber, R., & Huber, S. (2007). Atlas of Switzerland 2 — A highly interactive thematic national atlas. In W. Cartwright, M. P. Peterson, & G. Gartner (Eds.), *Multimedia Cartography* (pp. 161–182). Berlin, Heidelberg: Springer. Retrieved 2020-09-29, from https://doi.org/10.1007/978-3-540-36651-5_12

Siekierska, E. M., & Taylor, D. (1991, April). Electronic mapping and electronic atlases: new cartographic products for the information era - the electronic atlas of canada. *CISM journal*, *45*(1), 11–21. Retrieved 2020-09-29, from http://www.nrcresearchpress.com/doi/10.1139/geomat-1991-0002

Slocum, T. A., Sluter, R., Kessler, F., & Yoder, S. (2004, September). A Qualitative Evaluation of MapTime, A Program For Exploring Spatiotemporal Point Data. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *39*(3), 43–68. Retrieved 2020-10-04, from https://utpjournals.press/doi/10.3138/92T3-T928-8105-88X7

Stefanakis, E., & Peterson, M. P. (2006). Geographic Hypermedia. In E. Stefanakis, M. P. Peterson, C. Armenakis, & V. Delis (Eds.), *Geographic Hypermedia* (pp. 1–21). Berlin, Heidelberg: Springer Berlin Heidelberg. Retrieved 2020-08-23, from http://link.springer.com/10.1007/978-3-540-34238-0_1 (Series Title: Lecture Notes in Geoinformation and Cartography)

Stewart, D. W., & Shamdasani, P. N. (1990). *Focus groups: theory and practice* (No. v. 20). Newbury Park, Calif: Sage Publications.

Taylor, D. R. F. (2003). The Theory and Practice of Cybercartography" An Introduction. , 13.

Thomas, D. S. K., Mitchell, J. T., Scott, M. S., & Cutter, S. L. (1999, September). Developing a Digital Atlas of Environmental Risks and Hazards. *Journal of Geography*, *98*(5), 201–207. Retrieved 2020-08-10, from http://www.tandfonline.com/doi/abs/10.1080/00221349908978886

Tsou, M.-H. (2011, January). Revisiting Web Cartography in the United States: the Rise of User-Centered Design. *Cartography and Geographic Information Science*, *38*(3), 250–257. Retrieved 2020-05-15, from http://www.tandfonline.com/doi/abs/10.1559/15230406382250

Tsou, M.-H., & Curran, J. M. (2008). User-Centered Design Approaches for Web Mapping

Applications: A Case Study with USGS Hydrological Data in the United States. In M. P. Peterson (Ed.), *International Perspectives on Maps and the Internet* (pp. 301–321). Berlin, Heidelberg: Springer Berlin Heidelberg. Retrieved 2020-05-15, from http://link.springer.com/10.1007/978-3-540-72029-4_20 (Series Title: Lecture Notes in Geoinformation and Cartography)

van Kleunen, M., Dawson, W., Essl, F., Pergl, J., Winter, M., Weber, E., ... Pyšek, P. (2015, September). Global exchange and accumulation of non-native plants. *Nature*, *525*(7567), 100–103. Retrieved 2020-03-30, from http://www.nature.com/articles/nature14910

Vozenilek, V. (2019, July). Atlases and Systems Theory within Systematic Cartography. *Abstracts of the ICA*, *1*, 1–2. Retrieved 2020-09-15, from https://www.abstr-int-cartogr-assoc.net/1/386/2019/

Wang, L. (2017, August). Heterogeneous Data and Big Data Analytics. *Automatic Control and Information Sciences*, *3*(1), 8–15. Retrieved 2020-10-07, from http://pubs.sciepub.com/acis/3/1/3/index.html

Weigelt, P., König, C., & Kreft, H. (2020, January). GIFT – A Global Inventory of Floras and Traits for macroecology and biogeography. *Journal of Biogeography*, *47*(1), 16–43. Retrieved 2020-06-27, from https://onlinelibrary.wiley.com/doi/abs/10.1111/jbi.13623

Šavrič, B., Jenny, B., White, D., & Strebe, D. R. (2015, October). User preferences for world map projections. *Cartography and Geographic Information Science*, *42*(5), 398–409. Retrieved 2020-09-08, from http://www.tandfonline.com/doi/full/10.1080/15230406.2015.1014425

Appendices

Interactive Atlas Source Code

The source code for this interactive atlas is available online, along with the data used at https://github.com/sebastian-ch/glonafAtlas.

Just the GloNAF data can be found at https://idata.idiv.de/DDM/Data/ShowData/257.

```html
<!--
    LANDING PAGE INDEX.HTML
    Created by Sebastian Hancock
-->
<!DOCTYPE html>
<html lang="en">

<head>
    <!-- <meta http-equiv="Content-Security-Policy" content="default-src *; style-src 'self' 'unsafe-inline'; script-src 'self' 'unsafe-inline' 'unsafe-eval' http://www.google.com">

    <meta charset="UTF-8">
    <link rel="shortcut icon" href="favicon.ico?" type="image/x-icon"> -->



    <link rel="apple-touch-icon" sizes="180x180" href="/glonafAtlas/favicons/apple-touch-icon.png">
    <link rel="icon" type="image/png" sizes="32x32" href="/glonafAtlas/favicons/favicon-32x32.png">
    <link rel="icon" type="image/png" sizes="16x16" href="/glonafAtlas/favicons/favicon-16x16.png">

    <!-- Global site tag (gtag.js) - Google Analytics -->
    <script async src="https://www.googletagmanager.com/gtag/js?id=UA-90564282-7"></script>
    <script>
        window.dataLayer = window.dataLayer || [];

        function gtag() { dataLayer.push(arguments); }
        gtag('js', new Date());
        gtag('config', 'UA-90564282-7');

    </script>



    <meta name="viewport" content="width=device-width, initial-scale=1.0">
    <title>Atlas Home</title>



    <style>
        body {
            margin: 0;
            padding: 0;
            text-align: center;
            font-family: Calibri, sans-serif;
            font-size: 14px;
            font-style: normal;
            font-variant: normal;
            font-weight: 700;
            line-height: 26.4px;

        }

        #headerImg {
            width: 607px;
            height: 224px;
        }

        #header {
            background: #cfe7d6;
        }

        ul {
            border-top: 1px solid black;
            border-bottom: 1px solid black;
            display: flex;
            list-style-type: none;
            font-size: 22px;
```

```html
<!--PLANT VIEW INDEX-->
<!DOCTYPE html>
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<head>

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    <!--<link rel="shortcut icon" href="favicon.ico?" type="image/x-icon">
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    <meta http-equiv="Content-Security-Policy" content="default-src *; style-src 'self' 'unsafe-inline'; script-src 'self' 'unsafe-inline'
'unsafe-eval'"> -->

    <link rel="apple-touch-icon" sizes="180x180" href="/glonafAtlas/favicons/apple-touch-icon.png">
    <link rel="icon" type="image/png" sizes="32x32" href="../glonafAtlas/favicons/favicon-32x32.png">
    <link rel="icon" type="image/png" sizes="16x16" href="../glonafAtlas/favicons/favicon-16x16.png">

    <title>Plant View</title>
    <script src="https://d3js.org/d3.v5.min.js" type="text/javascript"></script>
    <script src="https://d3js.org/d3-geo-projection.v2.min.js" type="text/javascript"></script>
    <script src="https://unpkg.com/textures@1.2.0/dist/textures.js" type="text/javascript"></script>
    <script src='https://cdn.jsdelivr.net/npm/lodash@4.17.19/lodash.min.js' type="text/javascript"></script>
    <script src="https://unpkg.com/topojson@3"></script>
    <script src="https://bundle.run/geojson-rewind@0.3.1"></script>

    <!--Object of all Plant Names-->
    <script src='pNames.js' type="text/javascript"></script>
    <script src="autoc.js" type="text/javascript"></script>

    <style>
        body {
            font-family: Arial, Helvetica, sans-serif;
            background: whitesmoke;
            overflow: hidden;
        }

        #map {
            width: 90%;
            margin: 10px auto 10px auto;
        }

        form {
            width: 100%;
            text-align: center;
        }

        .autocomplete {
            /*the container must be positioned relative:*/
            position: relative;
            display: inline-block;
        }

        input,
        button {
            border: 1px solid transparent;
            background-color: #f1f1f1;
            padding: 10px;
            font-size: 16px;
        }

        button {
            position: absolute;
            border: 1px solid gray;

            left: 10px;
```

```html
<!--WORLD VIEW INDEX-->
<!DOCTYPE html>
<html lang="en">

<head>

   <meta charset="UTF-8">

   <link rel="apple-touch-icon" sizes="180x180" href="/glonafAtlas/favicons/apple-touch-icon.png">
   <link rel="icon" type="image/png" sizes="32x32" href="/glonafAtlas/favicons/favicon-32x32.png">
   <link rel="icon" type="image/png" sizes="16x16" href="/glonafAtlas/favicons/favicon-16x16.png">
   <!--<link rel="shortcut icon" href="favicon.ico?" type="image/x-icon">
   <meta name="viewport" content="width=device-width, initial-scale=1.0">
   <meta http-equiv="Content-Security-Policy" content="default-src *; style-src 'self' 'unsafe-inline'; script-src 'self' 'unsafe-inline'
'unsafe-eval'"> -->
   <title>World View</title>
   <script src="https://d3js.org/d3.v5.min.js" type="text/javascript"></script>
   <script src="https://d3js.org/d3-geo-projection.v2.min.js" type="text/javascript"></script>
   <script src="https://unpkg.com/textures@1.2.0/dist/textures.js" type="text/javascript"></script>
   <script src='https://cdn.jsdelivr.net/npm/lodash@4.17.19/lodash.min.js' type="text/javascript"></script>
   <script src="https://unpkg.com/topojson@3"></script>
   <script src="https://bundle.run/geojson-rewind@0.3.1"></script>
   <script src='https://cdnjs.cloudflare.com/ajax/libs/spin.js/2.0.1/spin.min.js'></script>

   <script src='../universalData/familyNames.js' type="text/javascript"></script>
   <script src="autoc.js"></script>
   <style>
      body {
         margin: 0;
         padding: 0;
         font-family: Calibri, Arial, sans-serif;
         overflow: hidden;
         background: #dcdcdc;

      }

      p {
         width: 80%;
         margin: 10px auto 10px auto;
      }

      button {
         width: 80%;
         margin: 10px auto 10px auto;
         margin-top: 4px;
         margin-bottom: 4px;
         border: 2px solid black;
         text-align: center;
         padding: 5px;
      }

      select {
         margin-top: 4px;
         width: 80%;
         text-align: center;
      }

      button:hover {
         background-color: gray;
         cursor: pointer;
      }

      .parent {
         display: grid;
```

```html
<!--CONTINENT VIEW INDEX -->
<html>

<head>
    <!-- <meta http-equiv="Content-Security-Policy" content="default-src *; style-src 'self' 'unsafe-inline'; script-src 'self' 'unsafe-
inline' 'unsafe-eval' http://www.google.com">
    <link rel="shortcut icon" href="favicon.ico?" type="image/x-icon">
    <meta name="viewport" content="width=device-width, initial-scale=1.0">
-->
    <meta charset="utf-8">

    <title>Continent View</title>

    <style>
        body {
            padding: 0;
            margin: 0;
            background: #c6c6c6;

            overflow: hidden;
            font-family: Calibri, sans-serif;
        }

        h2 {
            color: whitesmoke;
        }

        #map {
            margin-top: 0px;
            left: 250px;
        }

        .parent {
            display: grid;
            grid-template-columns: minmax(150px, 17%) 1fr;
        }


        #sidebar {
            height: 100vh;
            background-color: whitesmoke;
            overflow-y: hidden;
            text-align: center;
        }

        .closebtn1 {
            position: absolute;
            top: 0;
            right: 25px;
            font-size: 28px;
            margin-left: 50px;
            background-color: #111;
            color: whitesmoke;
        }

        #sidebar-text {
            margin: 10px auto 10px auto;
            width: 80%;
            text-align: left;
            font-size: 15px;
        }

        .newMap {
            width: 80%;
```

```javascript
//adapted from http://w3schools-fa.ir/howto/howto_js_autocomplete.html
//used in all views

function autocomplete(inp, arr) {
  /*the autocomplete function takes two arguments,
  the text field element and an array of possible autocompleted values:*/
  var currentFocus;
  /*execute a function when someone writes in the text field:*/
  inp.addEventListener("input", function(e) {
    var a, b, i, val = this.value;
    /*close any already open lists of autocompleted values*/
    closeAllLists();
    if (!val) { return false; }
    currentFocus = -1;
    /*create a DIV element that will contain the items (values):*/
    a = document.createElement("DIV");
    a.setAttribute("id", this.id + "autocomplete-list");
    a.setAttribute("class", "autocomplete-items");
    /*append the DIV element as a child of the autocomplete container:*/
    this.parentNode.appendChild(a);
    /*for each item in the array...*/
    for (i = 0; i < arr.length; i++) {
      /*check if the item starts with the same letters as the text field value:*/
      if (arr[i].substr(0, val.length).toUpperCase() == val.toUpperCase()) {
        /*create a DIV element for each matching element:*/
        b = document.createElement("DIV");
        /*make the matching letters bold:*/
        b.innerHTML = "<strong>" + arr[i].substr(0, val.length) + "</strong>";
        b.innerHTML += arr[i].substr(val.length);
        /*insert a input field that will hold the current array item's value:*/
        b.innerHTML += "<input type='hidden' value='" + arr[i] + "'>";
        /*execute a function when someone clicks on the item value (DIV element):*/
        b.addEventListener("click", function(e) {
          /*insert the value for the autocomplete text field:*/

          inp.value = this.getElementsByTagName("input")[0].value;
          spinner.spin(target);
          /*close the list of autocompleted values,
          (or any other open lists of autocompleted values:*/
          closeAllLists();
        });
        a.appendChild(b);
      }
    }
  });

  /*inp.addEventListener('click', function(e) {
    console.log('hi')
    e.preventDefault();
  }) */
  /*execute a function presses a key on the keyboard:*/
  inp.addEventListener("keydown", function(e) {
    var x = document.getElementById(this.id + "autocomplete-list");
    if (x) x = x.getElementsByTagName("div");
    if (e.keyCode == 40) {
      /*If the arrow DOWN key is pressed,
      increase the currentFocus variable:*/
      currentFocus++;
      /*and and make the current item more visible:*/
      addActive(x);
    } else if (e.keyCode == 38) { //up
      /*If the arrow UP key is pressed,
      decrease the currentFocus variable:*/
      currentFocus--;
      /*and and make the current item more visible:*/
      addActive(x);
```

```javascript
//Continent View Sidebar Functions

function openPage(url) {
    window.open(url)
}

function infoCloseSide() {
    document.getElementById("infoPanel").style.visibility= "hidden";

}
```

```javascript
//Styling Functions for Continent View

function plain() {
    d3.selectAll('.continent').attr('fill', 'whitesmoke')
    d3.selectAll('.points').attr('fill', 'whitesmoke')
        .attr('r', '4px')

    document.getElementById('legend').innerHTML = ''
    document.getElementById('legend').style.visibility = 'hidden'
    document.getElementById('circleLegend').style.visibility = 'hidden'
}

function styleContinents(d) {

    var testProp;

    if (!d.properties) {
        testProp = Number(d.tdwg1);
    } else {
        testProp = d.properties.tdwg1
    }


    switch (testProp) {

        case 1:
            return '#fbb4ae'
            break;
        case 2:
            return '#b3cde3'
            break;
        case 3:
            return '#ccebc5'
            break;
        case 4:
            return '#decbe4'
            break;
        case 5:
            return '#fed9a6'
            break;
        case 6:
            return '#ffffcc'
            break;
        case 7:
            return '#fddaec'
            break;
        case 8:
            return '#bc80bd'
            break;
        default:
            return '#e5d8bd'

    }

}


function taxaCountStyle() {

    document.getElementById('circleLegend').style.visibility = 'hidden';


    d3.selectAll('.continent').transition()
        .duration(500).attr('fill', function(d) {
```

```javascript
//Asia-temperate functions

function justAsiaT() {

    document.getElementById('form').style.visibility = 'visible'
    document.getElementById('panel').style.visibility = 'visible'
    document.getElementById('mapTitle').style.visibility = 'hidden';
    document.getElementById('circleLegend').style.visibility = 'hidden';
    document.getElementById('legend').style.visibility = 'hidden';

    var div = document.getElementById('map')

    //closeSide();

    while (div.firstChild) {
        div.removeChild(div.firstChild)
    }

    var promises = [
        d3.json('../continentView/continent-geojsons/asia-temperate/asiaT1.geojson'),
        d3.csv('../continentView/continent-geojsons/asia-temperate/asiaTPoints1.csv')
    ]

    if (worldViewFilesData.asiaT == null) {

        Promise.all(promises).then(function(values) {

            worldViewFilesData.asiaT = values[0];
            worldViewFilesData.asiaTPoints = values[1]
            addToMap(values[0], values[1]);
        })

    } else {
        addToMap(worldViewFilesData.asiaT, worldViewFilesData.asiaTPoints)
    }

    function addToMap(data, points) {


        var svg = d3.select("#map")
            .append("svg")
            .attr("width", width)
            .attr("height", height)

        var g = svg.append("g");

        var projection = d3.geoRobinson().rotate([270,0])
            .fitSize([width - 50, height - 50], data)

        var geoPath = d3.geoPath()
            .projection(projection);

        var graticule = d3.geoGraticule().step([10, 10])


        svg.append('g')
            .selectAll("path")
            .data(data.features)
            .enter()
            .append("path")
            .attr('class', 'continent asiaT')
            .attr("d", geoPath)
            .attr('fill', '#e6dccc')
            .attr('stroke', '#ababab')
            .attr('stroke-width', '0.3')
```

```javascript
//Africa functions


function justAfrica() {

  //document.getElementById('mapTitle').style.visibility = 'hidden';
  document.getElementById('form').style.visibility = 'visible'
  document.getElementById('panel').style.visibility = 'visible'
  document.getElementById('mapTitle').style.visibility = 'hidden';
  document.getElementById('circleLegend').style.visibility = 'hidden';
  document.getElementById('legend').style.visibility = 'hidden';


  var div = document.getElementById('map')

  //closeSide();

  while (div.firstChild) {
    div.removeChild(div.firstChild)
  }

  var files = [
    d3.json('../continentView/continent-geojsons/africa/africa3.geojson'),
    //d3.csv('../continentView/continent-geojsons/africa/africaislands1.csv'),
    d3.csv('../continentView/continent-geojsons/africa/africaPointsW.csv')

  ]

  if (worldViewFilesData.africa == null) {

    Promise.all(files).then(function(values) {
      worldViewFilesData.africa = values[0];
      //worldViewFilesData.africaislands = values[1];
      worldViewFilesData.africaPoints = values[1]

      addToMap(values[0], values[1])
    })

  } else {
    addToMap(worldViewFilesData.africa, worldViewFilesData.africaPoints)
  }

  function addToMap(polys, points) {
    //console.log(polys)


    svg = d3.select("#map")
      .append("svg")
      .attr("width", width)
      .attr("height", height)
      .attr('class', 'africaMap')

    var g = svg.append("g");

    var projection = d3.geoMercator()
      .fitSize([width - 50, height - 50], polys)

    var geoPath = d3.geoPath()
      .projection(projection);

    var graticule = d3.geoGraticule().step([10, 10])

    svg.append('g')
      .selectAll("path")
      .data(polys.features)
      .enter()
```

```
//Asia-tropical functions

function justAsiaTrop() {

    document.getElementById('form').style.visibility = 'visible'
    document.getElementById('panel').style.visibility = 'visible'
    document.getElementById('mapTitle').style.visibility = 'hidden';
    document.getElementById('circleLegend').style.visibility = 'hidden';
    document.getElementById('legend').style.visibility = 'hidden';

    var div = document.getElementById('map')

    while (div.firstChild) {
        div.removeChild(div.firstChild)
    }

    var promises = [
        d3.json('../continentView/continent-geojsons/asia-tropical/asia-trop.geojson'),
        d3.csv('../continentView/continent-geojsons/asia-tropical/points.csv')
    ]

    if (worldViewFilesData.asiaTrop == null) {

        Promise.all(promises).then(function(values) {

            worldViewFilesData.asiaTrop = values[0];
            worldViewFilesData.asiaTropPoints = values[1]
            addToMap(values[0], values[1]);
        })

    } else {
        addToMap(worldViewFilesData.asiaTrop, worldViewFilesData.asiaTropPoints)
    }


    function addToMap(data, points) {

        var svg = d3.select("#map")
            .append("svg")
            .attr("width", width)
            .attr("height", height)

        var g = svg.append("g");

        var projection = d3.geoMercator()
        //projection.fitSize([width,height], data)
        projection.fitExtent([
            [10, 10],
            [width, height]
        ], data)

        var geoPath = d3.geoPath()
            .projection(projection);

        var graticule = d3.geoGraticule().step([10, 10])

        svg.append('g')
            .selectAll("path")
            .data(data.features)
            .enter()
            .append("path")
            .attr('class', 'continent asiaTrop')
            .attr("d", geoPath)
            .attr('fill', '#e6dccc')
            .attr('stroke', '#ababab')
            .attr('stroke-width', '0.3')
```

```javascript
//Europe Functions

function justEurope() {

    document.getElementById('form').style.visibility = 'visible'
    document.getElementById('panel').style.visibility = 'visible'
    document.getElementById('mapTitle').style.visibility = 'hidden';
    document.getElementById('circleLegend').style.visibility = 'hidden';
    document.getElementById('legend').style.visibility = 'hidden';

    var div = document.getElementById('map')

    while (div.firstChild) {
        div.removeChild(div.firstChild)
    }

    var promises = [
        d3.json('../continentView/continent-geojsons/europe/europe2.json'),
        d3.csv('../continentView/continent-geojsons/europe/points.csv'),

    ]

    if (worldViewFilesData.europe == null) {

        Promise.all(promises).then(function(values) {

            worldViewFilesData.europe = values[0];
            worldViewFilesData.europePoints = values[1]
            addToMap(geojsonRewind(values[0], true), values[1]);

        })

    } else {
        addToMap(worldViewFilesData.europe, worldViewFilesData.europePoints)
    }


    function addToMap(data, points) {

        var svg = d3.select("#map")
            .append("svg")
            .attr("width", width)
            .attr("height", height)

        var g = svg.append("g");

        //console.log(worldViewFilesData.backdrop);

        var projection = d3.geoConicConformal()
        //projection.fitSize([width,height], data)
        projection.fitExtent([
            [50, 50],
            [width, height]
        ], data)

        var geoPath = d3.geoPath()
            .projection(projection);

        var graticule = d3.geoGraticule().step([10, 10])

        svg.append('g')
            .selectAll("path")
            .data(data.features)
            .enter()
            .append("path")
            .attr('class', 'continent europe')
```

```javascript
//NA functions

function justNA() {

    //document.getElementById('mapTitle').style.visibility = 'hidden';
    document.getElementById('form').style.visibility = 'visible'
    document.getElementById('panel').style.visibility = 'visible'
    document.getElementById('mapTitle').style.visibility = 'hidden';
    document.getElementById('circleLegend').style.visibility = 'hidden';
    document.getElementById('legend').style.visibility = 'hidden';

    var div = document.getElementById('map')

    //closeSide();

    while (div.firstChild) {
        div.removeChild(div.firstChild)
    }

    var promises = [
        d3.json('../continentView/continent-geojsons/na/naComplete.geojson'),
        d3.csv('../continentView/continent-geojsons/na/naPoints2.csv')
    ]

    if (worldViewFilesData.northamerica == null) {

        Promise.all(promises).then(function(values) {

            worldViewFilesData.northamerica = values[0];
            worldViewFilesData.naPoints = values[1]
            addToMap(values[0], values[1]);
        })

    } else {
        addToMap(worldViewFilesData.northamerica, worldViewFilesData.naPoints)
    }

    function addToMap(data, points) {


        var svg = d3.select("#map")
            .append("svg")
            .attr("width", width)
            .attr("height", height)

        var g = svg.append("g");

        var projection = d3.geoAitoff()
            .fitExtent([
                [0, -150],
                [width, height - 100]
            ], data)
            .rotate([103, -45, 0])
            .translate([width / 2, height / 2])

        var geoPath = d3.geoPath()
            .projection(projection);

        var graticule = d3.geoGraticule().step([10, 10])


        var data1 = svg.append('g')
            .selectAll("path")

            .data(data.features)
            .enter()
```

```javascript
//Pacific Island Functions

function justPc() {

    document.getElementById('form').style.visibility = 'visible'
    document.getElementById('panel').style.visibility = 'visible'
    document.getElementById('mapTitle').style.visibility = 'hidden';
    document.getElementById('circleLegend').style.visibility = 'hidden';
    document.getElementById('legend').style.visibility = 'hidden';

    var div = document.getElementById('map')

    while (div.firstChild) {
        div.removeChild(div.firstChild)
    }

    var promises = [
        d3.json('../continentView/continent-geojsons/pacific/pacific.geojson'),
        d3.csv('../continentView/continent-geojsons/pacific/points.csv')
    ]

    if (worldViewFilesData.pacficPoints == null) {

        Promise.all(promises).then(function(values) {

            worldViewFilesData.pacific = values[0];
            worldViewFilesData.pacificPoints = values[1]
            addToMap(values[0], values[1]);
        })

    } else {
        addToMap(worldViewFilesData.pacific, worldViewFilesData.pacificPoints)
    }


    function addToMap(data, points) {

        var svg = d3.select("#map")
            .append("svg")
            .attr("width", width)
            .attr("height", height)

        var g = svg.append("g");

        var projection = d3.geoMercator().rotate([180,0])
        //projection.fitSize([width,height], data)
        projection.fitExtent([[10,10], [width,height]], data)

        var geoPath = d3.geoPath()
            .projection(projection);

        var graticule = d3.geoGraticule().step([10, 10])

        svg.append('g')
            .selectAll("path")
            .data(data.features)
            .enter()
            .append("path")
            .attr('class', 'continent pacific')
            .attr("d", geoPath)
            .attr('fill', '#e6dccc')
            .attr('stroke', '#ababab')
            .attr('stroke-width', '0.3')

            svg.selectAll('circle')
            .data(points)
```

```javascript
//SA Functions

function justSa() {

    //document.getElementById('mapTitle').style.visibility = 'hidden';
    document.getElementById('form').style.visibility = 'visible'
    document.getElementById('panel').style.visibility = 'visible'
    document.getElementById('mapTitle').style.visibility = 'hidden';
    document.getElementById('circleLegend').style.visibility = 'hidden';
    document.getElementById('legend').style.visibility = 'hidden';

    var div = document.getElementById('map')

    while (div.firstChild) {
        div.removeChild(div.firstChild)
    }

    var promises = [
        d3.json('../continentView/continent-geojsons/sa/sa.geojson'),
        d3.csv('../continentView/continent-geojsons/sa/saPoints1.csv')
    ]

    if (worldViewFilesData.sa == null) {

        Promise.all(promises).then(function(values) {

            worldViewFilesData.sa = values[0];
            worldViewFilesData.saPoints = values[1]
            addToMap(values[0], values[1]);
        })

    } else {
        addToMap(worldViewFilesData.sa, worldViewFilesData.saPoints)
    }

    function addToMap(data, points) {


        var svg = d3.select("#map")
            .append("svg")
            .attr("width", width)
            .attr("height", height)

        var g = svg.append("g");

        var center = [-36.07, 158.00]

        var projection = d3.geoMercator()
            .fitSize([width - 50, height - 50], data)

        var geoPath = d3.geoPath()
            .projection(projection);

        var graticule = d3.geoGraticule().step([10, 10])


        svg.append('g')
            .selectAll("path")
            .data(data.features)
            .enter()
            .append("path")
            .attr('class', 'continent sa')
            .attr("d", geoPath)
            .attr('fill', '#e6dccc')
            .attr('stroke', '#ababab')
            .attr('stroke-width', '0.3')
```