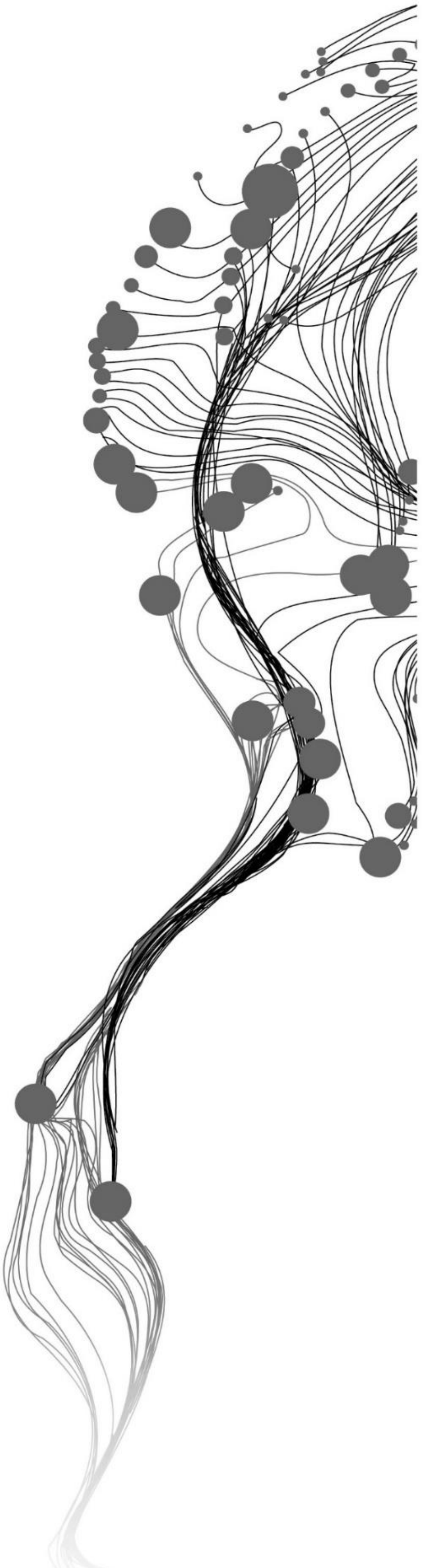
MAPPING FLOWS OF BENEFITS FROM MARINE ECOSYSTEMS ACROSS THE GLOBE

AN INTERACTIVE WEB MAPPING APPLICATION

NJERI MURAGE
June 2020

SUPERVISORS:
dr. E. Drakou
drs. B.J. Köbben



MAPPING FLOWS OF BENEFITS FROM MARINE ECOSYSTEMS ACROSS THE GLOBE

AN INTERACTIVE WEB MAPPING APPLICATION

NJERI MURAGE
Enschede, The Netherlands, June 2020

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Geoinformatics

SUPERVISORS:
dr. E. Drakou
drs. B.J. Köbben

THESIS ASSESSMENT BOARD:
prof.dr. M.J. Kraak (Chair)
dr. ir. Nynke Schulp (External Examiner, Faculty of Science, Environmental Geography, VU Amsterdam)

ABSTRACT

The significance of the benefits marine ecosystems offer to society has driven research towards quantification and mapping of Marine Ecosystem Services (MES) and the benefit flows to society. Today, the flow of benefits occurs across distances and boundaries allowing marine resources to be appreciated across the globe. Consequently, mapping the distribution and global flows of marine resources has become paramount in better understanding their importance globally and essential for their use in decision making. To achieve the latter, there is an emergent need for a tool for sharing and efficiently communicating this information. Up to now, the types of maps produced in this domain are mostly static, failing to capture the full picture on the global distribution of these benefits, while their actual and documented use in decision-making has been very limited. Following up on research conducted on user requirements for Ecosystem Service maps, I explored the efficiency of interactive web mapping to visualize the flow of benefits from marine resources to society. The aim of this thesis was to use and develop novel methods of interactive mapping to create a better communication tool for sharing information on the benefits society gets from marine resources, for decision-makers.

I designed, built, implemented, and tested an interactive flow map prototype for global flows of purse seine tuna fisheries from the West and Central Pacific Ocean (WCPO) region. Such flows are a type of data that is characteristic of complex branching Origin-Destination (OD) data which requires employing new methods. To achieve this, I developed an interactive web mapping application with the use of (carto-)graphic design principles following a user-centred focus in design and implementation. The methodology adopted a User-Centred Design approach where I first started with a user requirement analysis with selected end-users specific to ecosystem services and the WCPO region. Secondly, I systematically organized and restructured the available data in the form of origin-destination tables which allowed us to build flow maps. I then designed an interactive web map application and implemented a prototype using web map programming languages such as JavaScript and D3.js. Lastly, a two-round testing with the selected end-users was carried out to test the usability of the prototype for the chosen users and determine if the application serves the goals and use purpose.

Based on the outputs of our analysis and from usability testing, an interactive web mapping application for querying and visualizing MES economic flow benefits proved to have a significant impact in informing more efficiently the decision-making process while raising awareness and improving communication. It is the first time that information related to marine resource benefit distribution is visualized in such a way and tested by users with decision-making power. The scientific methods applied to create this web mapping application, introduced a novel interactive flow map application that visualized a unique type of branching origin-destination data to the field of web cartography, with the main innovation lying on the ability to dynamically and interactively change steps of branching flow maps in the supply value chain based on the user. The produced web mapping application could be further taken up and modified for application in other areas of work that involves flow mapping of similar complex networks such as global value supply chains or flows of other ecosystem services.

Keywords: Ecosystem Service, Marine Ecosystem Service, Interactive Web Mapping, Origin-Destination Data, Flow Mapping, User-centered design.

ACKNOWLEDGMENTS

This research would not have been possible without the support in the form of advice, supervision, guidance, and prayers from my supervisors, family, and friends. I would like to express my deepest gratitude for the people who played a crucial role in this journey.

Firstly, I would like to thank the Almighty God for courage, wisdom, strength, and most importantly good mental and physical health during the period of writing this thesis. There are times it may have been difficult, but His grace saw me through to the finish.

In a great way, I want to sincerely thank my supervisors, dr. E. Drakou and drs. B.J. Köbben., for being great and supportive mentors in my professional and technical work. Their guidance in reviewing my work, providing feedback and ideas, and their consistency in enquiring about my progress encouraged me to keep working hard. I thank them for trusting in my capabilities and for being patient with me in assisting me during this period.

In a special way, I would like to thank Robert Ohuru, my friend and mentor in the field of geospatial programming who has guided me through the technical challenges I faced when implementing this project. For his patience with teaching me and helping me solve technical problems and for his great advice. I am also greatly indebted to the D3 online instructors and slack community from which I built the fundamental basis of my technical skills for this work.

My gratitude and appreciation go out to my loving parents Maina Murage and Roselinah Murage and my siblings Wanjohi, Nombuyiselo, Temba, and Muthomi for being very supportive of my work, giving me great advice, for their prayers and for enduring my absence during this period.

Lastly to my friends Sarah, Tomiwa, Caroline, Ivy, Waringa, Esther and many who I cannot mention, your comfort, encouragement, prayers, and advice have played an important role throughout this research.

My deepest appreciation goes out to you all.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

API	Application Programming Interface
CGI	Common Gateway Interface
CSS	Cascading Style Sheets
D3	Data Driven Documents
DOM	Document Object Model
ES	Ecosystem Service
ESP-VT	ESP Visualization Tool
FFA	Fisheries Forum Agency
FSM	Federated States of Micronesia
GDP	Gross Domestic Product
HCI	Human-computer interaction
HTML	Hypertext Mark-up Language
HTTP	Hypertext Transfer Protocol
ISO	International Organization for Standardization
IDE's	Integrated Development Environments
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
MAES	Mapping and Assessment of Ecosystems and their Services
MES	Marine Ecosystem Services
MSPD	Marine Spatial Planning Directive
MT	Metric tons
OD	Origin-Destination
PICs	Pacific Island Countries
PNA	Parties to the Nauru Agreement
PNG	Papua New Guinea
SBA	Service Benefiting Area
SCA	Service Connecting Area
SIDS	Small Island Developing States
SPA	Service Providing Area
SVG	Scalable Vector Graphics
TEEB	The Economics of Ecosystems and Biodiversity
TTT	Type by task taxonomy
UCD	User-centred Design
UE	Usability Engineering
UI	User Interface
UX	User Experience
VDS	Vessel Day Scheme
WCPFC	The Western and Central Pacific Fisheries Commission
WCPO	West and Central Pacific Ocean

1. INTRODUCTION

1.1. Background Information and Motivation

The world's oceans and coasts contribute significantly to human well-being through, among others, economic livelihood, food supply, recreation, and community cohesion (Burkhard & Maes, 2017; Drakou, Virdin, & Pendleton, 2018). In today's era of globalization, the distance between places and boundaries are becoming less significant, therefore allowing benefits and contributions from the seas and oceans to be appreciated across the globe irrespective of regional or national boundaries (Drakou et al., 2018). The significant benefits marine ecosystems offer to society has driven research towards the assessment of Marine Ecosystem Services (MES) which refers to the benefits obtained from a marine system e.g. food provision (Burkhard & Maes, 2017). Within the assessment of MES, mapping of these services has been set as a core priority, to better understand the ecosystem, its dynamics, and the countries or regions where these benefits are received (Burkhard & Maes, 2017). The objective of MES mapping is, among others, to assist the decision-making process related to access, use, and control of the benefits (Drakou et al., 2018). Past research has shown that within ES Mapping and assessments there is an implementation gap between the research output and the actual use in practice (Drakou, Kermagoret, et al., 2017; Palomo et al., 2018; Ruckelshaus et al., 2015). This results in the need for taking scientific approaches and design principles.

MES maps provide a powerful means to visualize spatial information and to communicate complex spatial phenomena for actual use in practice (Rühringer, 2018). Most MES maps currently produced are static Rühringer, (2018) Beyond the use of static visuals, interactive mapping proves to be an effective tool to increase transparency in monitoring (Kraak & Ferjan, 2010) and management of traded goods, food systems and allow food traceability to improve by better communicating spatial (Drakou et al., 2018). Still, this type of interactive mapping has not been applied so far in this domain (Rühringer, 2018), although user requirement analysis has shown that there is a need for this. The last decades have seen a rise in mapping ecosystem services due to their value in spatially prioritizing areas and/or to aid in decision making. The reason for this is that mapping ES is essential to understand the significant contribution of ecosystems to human wellbeing and to support various policies that have an impact on natural resources. However, the progress and state of this mapping has been relatively slow and Rühringer, (2018)'s work on user requirement and usability analysis identifies a major gap on the use of static maps for visualizing ES. Rühringer, (2018) suggests as one of the outcomes that beyond the gap in static maps, there is a need for employing interactive based web-mapping of ES for capturing dynamic information on ES spatial distribution.

According to Burkhard & Maes, (2017) the services generated by an area irrespective of its actual use are known as Ecosystem Service (ES) supply. These services are appreciated at a benefiting area by the society otherwise known as ecosystem benefit (Burkhard & Maes, 2017). What links these two i.e., the "amount" of ES used by society or "flowing" to the beneficiaries is called ES flow. There are many definitions for flows and other ES terms, notwithstanding the differences, ES flow is used in this research to depict the amount of ecosystem services mobilized from a specific area at a given time to the benefiting area (Potschin, Haines-young, & Jax, 2014). All these aspects of ES are quantified and measured through sets of indicators that vary in terms of complexity, applicability, data needs, or scalability. Many of these indicators are spatially explicit and are therefore used for mapping ES. An example of *supply indicators* are fish weight caught at the resource waters, an example of a *demand indicator* is the amount of fish consumed by a region or the monetary value of consumption and examples of *flow indicators* are the fish catch origin or the percentage of fish harvest that is mobilized to a region for processing (Drakou et al., 2018). Although supply and demand are well studied, quantified, and mapped, ES flows are less studied (Burkhard & Maes, 2017), especially when it comes to the ES supplied by marine systems. Many of the ES relate also to traded goods that flow to beneficiaries in multiple locations, spanning across other marine but also terrestrial and inland regions. Marine ecosystems are inherently characterized by varying scales where demand may be from a local region and the benefit experienced on a national scale.

Ecosystem service flows tend to be dynamic over time and complex where multiple locations experience the cost and benefit of demand-driven from different multiple locations. Drakou et al., (2018) classifies flows in the WCPO region in 3 categories: one-to-one, closed-loop, and open-loop flows. In the case of WCPO, benefiting and provisioning areas may be different or the same as the initial location of demand and may include intermediary agents that also benefit from the ES. The heterogeneity of these flows is thus challenging to capture on static maps (Burkhard & Maes, 2017; Drakou et al., 2018). As a result, scientists are faced with the challenge of providing suitable methods to visualize large complex and dynamic systems. Hence challenges arise, such as missing data for different scales of regions or choice of the level of detail to focus on. This is a major limitation when using static maps as one should decide which scale and details best fit the data to be visualized and this challenge can be addressed by interactive visualization. There have been attempts to create interactive online ES maps (Drakou et al., 2015), however, in the domain of ES mapping, this is still very new and underdeveloped with systems having very limited interactive functions (Rühringer, 2018).

Maps relevant to ES flows, are in many cases designed to visualize what in cartography is called origin-destination (OD) data. OD mapping is a way of representing spatial interactions such as the flows of data between pairs of spatial locations which can either be branching or non-branching (Boyandin, 2013). Flows of MES are characteristic of branching OD data since for example, the flows move from origin(start) locations to destination(end) locations with intermediary locations. Such spatial interactions involve movement and direction and are hence better visualized using interactive flow maps. Flow maps are types of maps that show interactions or flows between nodes or areas (Boyandin, 2013; Jenny et al., 2018). A few authors explore methods of interactive or automated creation of branching flow maps (Debiasi, Simões, & De Amicis, 2014; Jenny et al., 2017), however, this is yet to be adapted to MES and mapping branching OD data is still an underdeveloped field of cartography. In recent years, many OD datasets have become available, nonetheless, appropriate techniques and design principles are yet to be incorporated in the creation of visualizations (Boyandin, Bertini, Bak, & Lalanne, 2011)For example, by employing cartographic communication design principles (Kraak & Ferjan, 2010; Roth, 2013), using taxonomies of visualization (Shneiderman, 1996), employing design principles of OD flow maps such as those identified by Jenny et al., (2018) or having a User-centred Design (UCD) approach which considers the user's requirements.

With the recent advancement in mobile and web technology, web mapping applications with dynamic and interactive capabilities and functionalities have become increasingly popular and valuable as a medium of communication (Tolochko, 2016). Yet due to the unique and dynamic complexity of MES flows and the lack of expertise in the domain field (Palomo et al., 2018), interactively mapping these systems has not yet been explored (Rühringer, 2018). Still, this would be an added value to the decision-makers based on user requirement analysis done by Rühringer (2018). Interactive mapping involves the creation of digital maps in which the map reader has the freedom to dynamically change the view or map content displayed and is based on added functionalities such as zoom, search, query, etc. (Rühringer, 2018). In cartographic research static digital maps and paper maps remain essential, however providing interactivity means the map reader is empowered to create representations that best support their use context (Roth, 2013). A challenge that often arises is that many interactive web maps are either too complex or poorly designed to properly communicate information to users. In order to achieve a well-designed visual that clearly communicates, researchers should consider a set of design principles and approaches (Jenny et al., 2018), the type of data, as well as the end-user (Roth et al., 2017).

This research application is dual covering both the field of ecosystem services mapping and the field of cartography: it aims to cover the need for an effective tool for communication for decision-makers to understand the spatial distribution and flow of ES benefits from the oceans to society; while exploring novel scientific methods for the creation of a novel interactive branching flow map application. A limitation posed in ES Mapping and assessments is the implementation gap between the output and the actual use in practice (Drakou, Kermagoret, et al., 2017; Palomo et al., 2018; Ruckelshaus et al., 2015). This results in the need for new methods that consider scientific design principles. To my knowledge past research has not been done on how to represent flow benefits of ecosystem services globally hence proving to bring a novel idea within the two domains of academia.

In this MSc research, I explore the development of an interactive web mapping application for the case of the purse seine tuna fishery in the West and Central Pacific Ocean (WCPO) region focusing on the Pacific Possible World Bank project on Tuna fisheries for Pacific Island Countries (World Bank and Nicholas Institute, 2016). The information on this fishery comes from reports produced in regional projects and is usually presented in lists, numbers, and charts which fail to show a holistic picture. Hence the contributions to the global well-being of a local fishery in Pacific Island countries are hardly considered in the fisheries management or the decision-making at a trans-national to local level (Hamilton, Lewis, McCoy, Havice, & Campling, 2011). Improving the way, we map this data is the first step towards communicating this information. An interactive web mapping application for querying and visualizing marine flow benefits will have a significant impact on decision-support systems and communication.

1.2. Problem Statement

The significance of the benefits marine ecosystems offers to society e.g., fisheries, food, recreation, among others, has driven research towards the so-called Marine Ecosystem Services (MES) and specifically towards mapping marine benefit flows to society. The distribution of these resources occurs across distances, places, and boundaries allowing resources from the seas and oceans to be appreciated across the globe. Therefore, mapping the distribution of marine resources has become paramount in better understanding their importance globally and essential for their use in decision making. To do that, there is an emergent need for an effective tool for using, analysing and communicating this information. Up to now, the types of maps produced in this domain are mostly static, failing to capture the full picture on the distribution of these benefits, while their actual and documented use in decision-making has been very limited.

Following up on the Rühringer, (2018)'s work on user requirement analysis this research explores the efficiency of interactive web mapping as a means to visualize the flow of benefits from marine resources to society. The heterogeneity of the flows in the global supply chain is difficult to capture on static maps. They are unique and may be described as a type of branching origin-destination (OD) data where the flows of data between pairs of spatial locations are seen to branch outwards in more than one step or loopback. Such spatial interactions involving movement and direction are better visualized using interactive flow maps. As discussed above, few authors have investigated interactive or automated creation of branching flow maps and this has to my knowledge never been explored in marine ecosystem services. In this thesis, "I seek to map marine ES flow benefits across the globe and visualize them through an interactive web mapping application to bring out valuable, possibly hidden, insights and information to the end-user."

1.3. Research Identification

1.3.1. Research Objective

The main objective of this research is to develop and test with selected end-users an interactive web mapping application to visualize the flow of marine ecosystem services from the service supplying area to the service benefiting area across the globe. This is divided into four sub-objectives and related research questions. The sub-objectives are as follows:

1. To analyse formerly defined user requirements and delineate as well as systematically organize the set of suitable indicator data for mapping of MES flows in the WCPO region.
2. To design an interactive web mapping application for the visualization of marine ES flows.
3. To build and implement an interactive web mapping prototype to facilitate visualization of MES flows.
4. To test the usability of the prototype application with selected end-users.

1.3.2. Research Questions

RQ 1: To analyse formerly defined user requirements and delineate as well as systematically organize the set of suitable indicator data for mapping of MES flows in the WCPO region.

i. Which are the requirements by the end-users for the system based on analysis of user research to communicate marine ES flows for the selected case?
ii. Which is the relevant ES indicator data and in what way shall this be organised based on user requirements in preparation for data storage and distribution?

RQ 2: To design an interactive web mapping application for the visualization of marine ES flows.

i. What technologies are needed to design an interactive web mapping application for marine fish trade flows?
ii. What are the steps required in designing of the application?
iii. Which scientific guidelines and principles will be used in determining suitable geo-visualization approaches and cartographic designs based on the chosen set of indicator data for the end-user requirements?

RQ 3: To build and implement an interactive web mapping prototype to facilitate visualization of marine ES flows.

i. What are the desired functionalities and capabilities of the prototype by the end-users?
ii. What technologies and infrastructure are needed for building and implementing the prototype?
iii. What are the potential challenges or limitations in the design and implementation of the system?

RQ 4: To test the usability of the prototype application with selected end-users.

i. Which set of executable tasks will be required to assess the application's usability for the end-user?
ii. What are the potential limitations and recommendations for the improvement of the prototype for the end-user?
iii. What are the boundary conditions under which the application may be applied in other areas for future work?

1.4. Thesis Outline

Chapter 1 provides a general introduction to the context of the research and its motivation, outlines the problem statement and the objectives and research questions to address the problem.

Chapter 2 provides a literature review on ecosystem service and ecosystem service mapping by explaining key definitions, concepts, and frameworks used in ecosystems mapping as well as the current state of ES mapping and the challenges that arise. The chapter looks at a broader perspective of mapping and visualization techniques by introducing interactive web mapping designs guidelines and principles as well as introducing flow mapping concepts and origin-destination mapping. We also discuss the web mapping application process and implementation. The chapter lastly gives a scientific background on the users of geo-visualization products by discussing the use and user requirements and usability testing including the User-centred design principle, cartographic communication process, and user needs assessment.

Chapter 3 outlines the methodology applied for each stage of the research. Providing an overview of the project plan, describing the use case, the methods for user and user requirements, steps taken in data acquisition and pre-processing, the process to be taken in web map design and the methods of implementation, and finally the methods employed in usability testing and adaptations.

Chapter 4 presents a discussion of the outcomes of the user requirements analysis and provides the functional requirements for the web mapping application. We then discuss the conceptual web map designs and geo-visualization design choices and preliminary sketches. This is followed by a discussion on the implementation steps, technologies, and code frameworks used as well as describes the resulting prototype. Finally, the results on the empirical evaluation are discussed where usability testing of the prototype and adaptations are presented.

Chapter 5 provides the conclusions and recommendations for the research. The conclusion contains a discussion on the outcomes of the research, the answers to the guiding research questions for each objective, suggestions for design and implementation, limitations encountered with possible suggestions, and the recommendations for future work.

2. LITERATURE REVIEW

2.1. Ecosystem Services

This section briefly introduces the concepts and definitions around ecosystem services, the typologies and frameworks that have been adopted in this domain, the importance and role of ES in decision making, and its context in relation to marine social-ecological systems. I also discuss the work done on ecosystem service mapping and the running challenges in this domain.

2.1.1. Concepts and Definitions used in Ecosystem Services

The term ecosystem has been defined by Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), a joint global initiative of governments, society, and academia, as a "dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit"(Millennium Ecosystem Assessment, 2005, p. 49). **Ecosystem Services (ES)** has had several evolving definitions where frequently cited definitions include the "the benefits people obtain from ecosystems" (Millennium Ecosystem Assessment, 2005, p. 49) or "the direct and indirect contributions of ecosystems to human-wellbeing" by The Economics of Ecosystems and Biodiversity (TEEB) (Fisher et al., 2010, p. 12). Despite several definitions, this research will consider the one provided by IPBES as "nature contribution's to people" (Díaz et al., 2018). The term ecosystem services was originally coined in 1981, however in the 1990s is when it really evolved with several landmark publications on natures benefits (Burkhard & Maes, 2017). Over time the definition of this concept has evolved between economic and ecological domains. On the one hand, some definitions have focus on an ecological basis (Musso & Druica, 2019) where ES refers to the conditions and process of natural systems. On the other hand, TEEB focuses on the economic definition and refers to it as the direct and indirect contributions of ecosystems to human well-being (Fisher et al., 2010). Nonetheless, all definitions stress the link between ecosystems and human well-being.

Classification systems have been created to describe concepts and categories within the ecosystems to limit the complexity and organize the information into data and knowledge. Categorizing and defining these services is the first basis in the attempt to measure, map, or value them and to describe and understand the interactions of benefits between human and nature (Burkhard & Maes, 2017; Rühringer, 2018). Classification systems which have been adopted in the ecosystems include but are not limited to The Millennium Ecosystem Assessment 2005 built upon the goal of understanding the consequences of ecosystem change for the human-wellbeing (Díaz et al., 2018); the TEEB ecosystem framework which focuses on economics with the goal of making nature's values visible (TEEB, n.d.); The CICES framework as proposed Haines-Young & Potschin, (2013) that provides a classification framework on environmental accounting mainly for the EU extent, and the IPBES framework that has a Global scope focusing on Biodiversity and ES with a focus on local knowledge and stakeholder engagement.

In this research, I adopt the more recent IPBES framework as it is more relevant to the global scope. Beyond these frameworks, other tailored systems have been adapted to suit a region or end purpose and they can be ecosystem-specific or country-specific. In most cases, global ES frameworks and classifications need to be adapted to match the specific case, to target the type of ecosystem, and to consider the regional specificities. Consequently, the frameworks considered for the chosen case are: The IPBES Classification system which is suitable for the global extent and can be tailored for the specific case study to understand indicators of marine fish flows (Díaz et al., 2015; Drakou et al., 2018); The cascade model by Haines-Young

& Potschin, (2013) which denotes the relationship or "pathway" that goes from ecological structures and process to the well-being of people hence socio-ecological systems and The proposed integrated framework on ES supply chain by (Daw et al., 2016; Drakou et al., 2018) which focuses on the supply and benefit value chain to explain the case of marine flows. Some of these frameworks have been specifically tailored to explicitly consider spatial scales and the human-nature interaction. While ES literature has focused on the spatial differentiation of ecosystem services many frameworks do not reflect the spatial disconnect between marine ecosystems, therefore, works such the proposed integrated framework which examines existing knowledge from ES provision frameworks, spatially explicit and tele-coupled approaches are important (Drakou, Pendleton, Effron, Ingram, & Teneva, 2017). To carry out this research I explore these frameworks with the aim of understanding the context of the use case chosen to create a conceptual framework within which I demonstrate an interactive web application.

There are running concepts that are used in ecosystem services that enable us to understand the relationships in ecosystems and which play an important role in specifying the indicators for quantification or mapping of these systems. ES has multiple concepts such as the ecosystem supply, flow, and demand. According to Burkhard & Maes, (2017), Ecosystem Service (ES) **supply** is the amount of services generated by an area irrespective of its actual use by society. ES **flow** is the amount which is mobilized in an area at a given time and ES **demand** is the need that is generated for a specific ES society, stakeholder, or group. As mentioned in the introduction, flows in this research is meant to depict the amount of ecosystem services mobilized in a specific area at a given time from the supplying area to the benefiting area (Potschin et al., 2014). In this research the concept of flows of ES is the emphasis, however, we do not disregard the important role that ES supply and demand play in the creation of a flow. The concepts and their position in a social-ecological system can be explained in the diagram below (Syrbe, Schröter, Grunewald, Walz, & Burkhard, 2017; Rühringer, 2018).

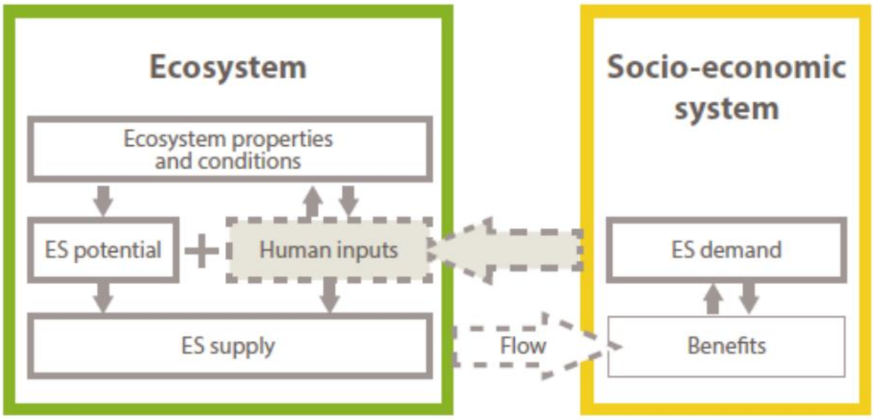


Figure 1: Ecosystem mapping concepts as described by (Syrbe et al., 2017)

The framework shown in Figure 1 shows that the ecosystem services are the flows depicted from ecosystems to socio-economic systems and that the socio-economic systems are the drivers that impact change in the ecosystem. The functions that flow in the socio-economic systems are the ecosystem services. These services contribute to human well-being through benefits and values, such as food. They can be measured in different ways such as monetary value or actual resource value. In addition to these concepts, understanding the spatial component of ecosystem service supply, flow, and demand as defined above, is crucial for a more complete information set that can be used for decision-making.

When considering the flows of ecosystem services, we look at the region from which the service is provided or supplied to and where the demand, which triggers the flow, is appreciated. These areas have been defined in research as Service Providing Area (SPA) which is "the spatial unit within which an ecosystem is provided," Service Benefiting Area (SBA) which refers to "the spatial unit where an ES flow is delivered to beneficiaries" and Service Connecting Area (SCA) which refers to the space connecting non-adjacent ES providing and benefiting areas (Syrbe & Walz, 2012). Researchers such as Serna-Chavez et al. (2014) have defined four types of relationships to account for the spatial interactions which are: 1) spatial co-currencies between the provisioning and benefiting area spatially; 2) benefiting extends beyond provisioning area; 3) the provisioning is connected with benefiting area through a connecting area and 4) a scale-divergent ES where provision and benefiting area are in different spatial scales e.g. from local to global (Drakou, Pendleton, et al., 2017). Marine social-ecological systems are characterised by several of these interactions, making the system complex to assess and map.

The significance of distant interactions between human and nature has been researched on extensively with a focus on terrestrial applications(Drakou, Pendleton, et al., 2017). These distant interactions in Marine Ecosystems have not been covered as widely (Drakou, Pendleton, et al., 2017), however still they have played an important role in governance mechanisms in different locations. Therefore, there is the need to map the benefits realised beyond the spatial bounds of the resource and show the distant interactions in these systems. The measures and indicators of ecosystem services as well as their extents whether global, regional, or local differ in various systems and to assess and map these ES, classification frameworks that have been provided in this research.

2.1.2. Marine Ecosystem Services

Researchers argue that much of the world's marine ecosystems when compared to terrestrial environments are poorly mapped and understood with the major reason being that marine ecosystems may not be spatially explicit (Drakou, Pendleton, et al., 2017). Moreover, the highly dynamic nature of these services presents spatial bound unique challenges such as different time and spatial resolutions, challenges in measuring as well as the accuracy of measurements, logical coherence, and consistency of the measurements of these services. Marine Ecosystems are unique in several aspects which presents a challenge as well as a need to employ new approaches and design methods to understand and map them. They are spatially distant, and benefits are realised beyond the resource bounds. Attempts to map spatially distant ecosystems and services have been very few (Drakou, Pendleton, et al., 2017) and though frameworks have been developed in the past modern map tools or applications such as interactive web mapping are yet to be adapted to the case of MES or ES in general (Rühringer, 2018).

Marine Ecosystem Services (MES) are the benefits obtained from marine ecosystems. Ecosystem Services are generally divided into 3 different categories: provisioning, regulating, and cultural services depending on the chosen framework (Burkhard & Maes, 2017). Tuna fish is food provided by marine ecosystem services and therefore falls under-provisioning service, where it offers benefits in terms of consumption and as an economic resource. MES benefits extend beyond the service providing area or spatial bounds to other locations, and they are measured at different spatial granularity. For example, tuna fish in the WCPO region is harvested in Papua New Guinea (PNG), which may be processed in Thailand and consumed in Europe, hence in retrospect, the benefits of the MES which is the tuna fish resource is realized across several locations in the globe. Therefore, the flow is the tuna fish catch mobilized to be processed and exported for consumption, supply is the fish caught at the resource location in PNG, and demand is the fish consumed at the market in Europe. Another challenge that commonly arises in MES mapping, is the lack of complete datasets over time and the level of spatial accuracy being is low. This, along with the mapping challenges mentioned above, require a specific understanding of how the services flow from supply to the benefiting area (Drakou et al., (2018).

2.1.3. Ecosystem Service Maps

Ecosystem service mapping is the spatial delineation of the ecosystems based on an agreed ecosystem typology and this depends on the mapping purpose and scale (Burkhard & Maes, 2017). The last decades have seen a rise in mapping ES due to their value in helping identify problems spatially and in priority areas. Maps are powerful for the communication of complex phenomena and can be used to support decision-making in policy, planning, monitoring, and management hence the growing need for them. Ecosystem service maps can be defined as the "cartographic representation(s) of (quantified) ecosystem service indicators in geographic space and time" (Burkhard & Maes, 2017, p. 370). Recently, the concept of ES mapping is increasingly becoming more and more valuable as a tool for policy and decision making (Burkhard & Maes, 2017, p. 201). Such examples include the UN initiative on Mapping Biodiversity and Ecosystem Services, the EU initiative on Mapping and Assessment of Ecosystems and their Services, among other global and national policies, initiatives and directives (Burkhard & Maes, 2017; Rühringer, 2018). The reason for this is that mapping ES is essential to understand the significant contribution of ecosystems to human wellbeing and to support various policies that have an impact on the resource. Healthy ecosystems play an important role as the fundamental basis for a resilient society and a sustainable economy (Burkhard & Maes, 2017). To ensure a healthy ecosystem we need to understand the actors or players involved. To do this, we can offer communication tools of this information by providing an interactive web mapping application that gives an overview of who are the actors involved in Marine Ecosystem Services, in what way they benefit from the service and how they are linked.

ES maps are of high political, societal, and economic relevance and following this, their compilation should use the logic and the well-founded knowledge from graphic semiology (Lorena, 2019). Based on the diversity of ES mapmakers, map-users, the complex topics to be displayed, and their high societal relevance, ES maps need to be designed with care. Well-constructed maps can properly communicate and explain complex ES phenomena. The growing popularity of ES mapping by the scientific community has led to tools enabling mapping for these services (Lorena, 2019). ES maps are produced through the use of different methods and for various purposes. Some of the main mapping purposes could be to carry out ES quantification, to understand ES dynamics, trend analysis, scenario analysis, to raise awareness, or for research purposes. The methods that have been used to map these services may include Participatory approaches such as interviews, focus groups, citizen science; Land-cover based approaches such as landscape metrics, look-up tables or expert-based methods; Remote sensing methods which may entail change detection or acquisition of ecological and social data; Modelling approaches that employ tools and technologies like InVEST, R ARIES among others or it could be a mix or integrated approach of the methods (Burkhard & Maes, 2017). Nevertheless, when defining the graphic representations, the aim should facilitate the understanding of the spatial phenomena while reflecting on the main spatial characteristics of the chosen service. It is thus vital to consider the types of representation or/and map types chosen to communicate the information.

Below are examples of some of the currently existing ES maps produced such as dot maps and choropleth maps (Figure 2 and Figure 3) which are the most common representations of ES maps seen from research such as the thesis by Rühringer, (2018) and Lorena, 2019). This research focuses on the visualization of the flows of marine ecosystems and therefore consideration has to be given to the characteristics of spatial interactions and links as well as distant relationships where the service benefit is seen to extend beyond the bounds of the service providing area. Hence when choosing the visualization to represent this data, flowline maps would be most suitable for this research.

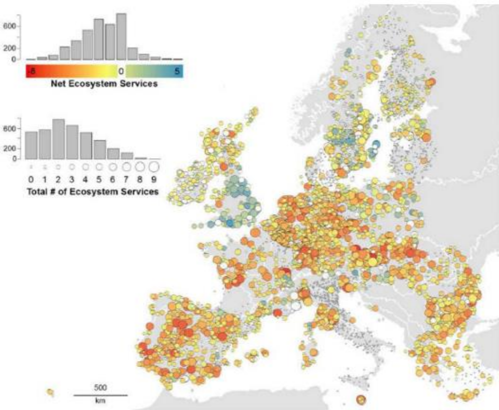


Figure 2: Proportional symbol map displaying the number and impact of ecosystem services where Special Protection Area for which due on pressure was reported due to the use of ecosystem services by (Ziv et al., 2018)

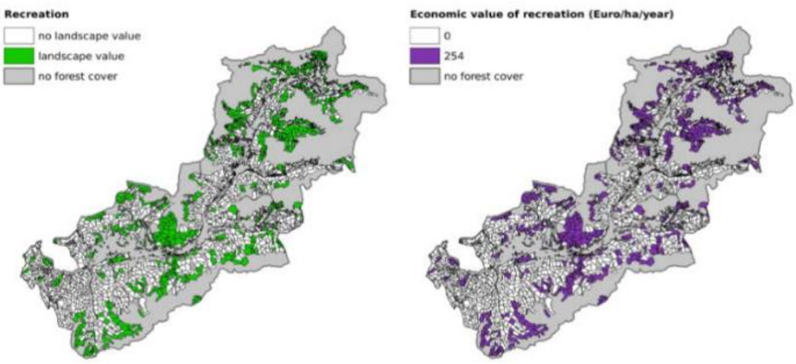


Figure 3: Chorochromatic map showing recreational value of research region and economic value (Häyhä, Franzese, Paletto, & Fath, 2015)

MES has been described to display a unique set of characteristics however there is limited research that focuses on the interactive nature of the flows where a majority mainly illustrates the service supply area. There have also been reviews summarizing the state of MES mapping such as research done by (Liquete et al., 2013) which found that very few studies, 3% of the 145 reviewed papers, produced maps of ecosystem services for marine and coastal ecosystem services. Some examples of existing MES maps previously produced to map ecosystem services include the choropleth static map showing the current level of service supply in Plymouth Sound to Fowey region, UK (see Figure 4) where the main focus was on providing information for local policies and plans and therefore, they mapped the marine habitats and level of service provision (Burkhard & Maes, 2017, p. 336). Another example of MES maps that exists is another choropleth static map for the Latvian territorial waters and Exclusive Economic Zone to denote significant areas for supply of provisioning, regulatory and cultural services and avoid their deterioration in the allocation of space for new developments in the sea where maps were used as a useful tool to assess possible impacts of alternative development scenarios (Burkhard & Maes, 2017, p. 337). Despite progress being made on research in ecosystem service maps, many of these maps explore the location of the resource or the habitats but hardly gives focus on the flows of benefits due to their complexity. Therefore, challenges that are yet to be addressed in this domain include mapping the flows of these resources to their demand.

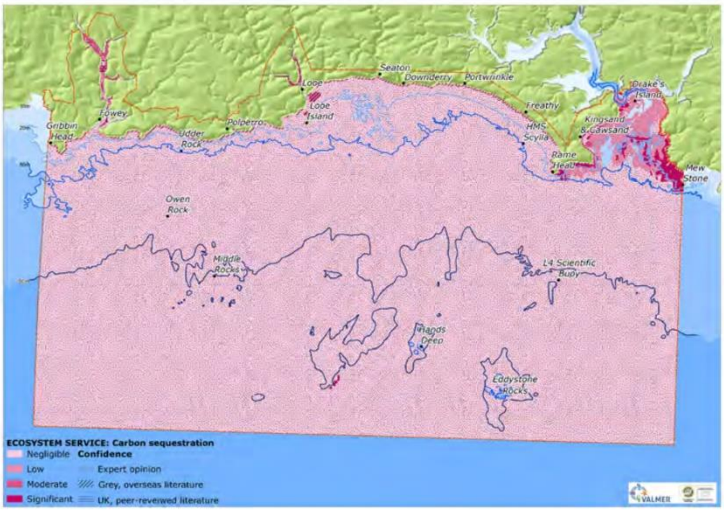


Figure 4: Carbon sequestration map in Plymouth Sound to Fowey, UK (Burkhard & Maes, 2017, p. 337)

Rühringer, (2018) points out from her research that the majority of the ES maps produced are either static or are interactive with limited functionality. Review of literature has shown attempts at interactive systems have only recently begun and still under development where only limited interactive functions exist such as zooming and toggle. There has been some research carried out to understand the flows and their interactions in a socio-ecological system by (Drakou et al., 2018), however, the challenge that arises is the fact that these are still static and hence give only a fraction of the information to be understood (Rühringer, 2018). Drakou et al., (2018) focused on visualizing the interactions that exist in MES flows i.e. one-to-one (referring to the same cost and benefit trade-off are observed among ES supply and demand areas), closed-loop (referring to the cases ES is demanded in one location which triggers flow to different spatial locations bearing costs and benefits and then having a final benefit at the place of demand)and open-loop interactions(which refers to multiple ES flows from multiple locations of supply and demand having flows in multiple locations with different agents) an example of the static map produced can be seen in Figure 5 by (Drakou et al., 2018). In this paper, I now highlight the need for more interactive systems. The focus is to now build upon the current static maps and create an interactive web mapping visualization tool that allows not only for an overall view of MES flows but gives further exploration capabilities.

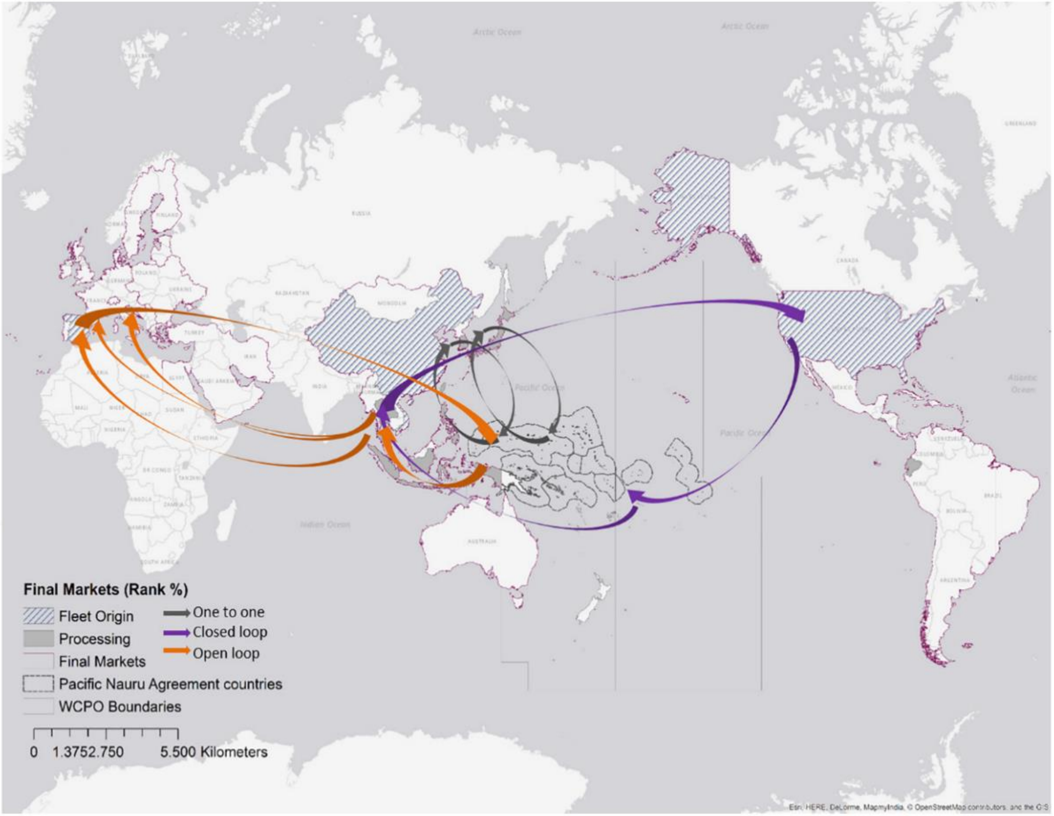


Figure 5: Flow map showing the global distribution and flows of economic costs and benefits generated by the purse-seine tuna fishery of WCPO region by (Drakou et al., 2018)

While most of the already produced maps are static in nature some web maps do exist. An example is the ESP Visualization Tool (ESP-VT) which is an online web portal or catalogue that allows for uploading, downloading, and querying of spatial information for ES (Burkhard & Maes, 2017). Though the ES community has progressed to static web mapping such as this tool, what is definitely not yet available is interactive web mapping.

In conclusion, many challenges are seen in ES mapping which is to be addressed by this research. A question that often arises relates to what ES maps should express the supply, flows, or demand. ES flows are generally dynamic over time and space in the case of MES and therefore difficult to capture on maps. The majority of ES maps do not visualize the actual flows and interrelationships between the supply and demand but mainly capture the location of habitat or resource to visualize supply. The challenge that is specific to the MES domain is that they are highly dynamic in nature, spatial resolutions differ and the services are spatially-distant hence visualizing these flows requires a global approach to understand the benefits, interrelationships/links and the key actors involved. MES or ES flows, in general, have not been visualized before in an interactive web map, and hence the novelty of this research is to create such a communication tool that can address these challenges and research gaps in the domain of MES.

2.2. Mapping and Visualization Techniques

This section entails a discussion on interactive and static web mapping history, interactive web mapping techniques, the principles, methods, and the general guidelines used in creating an interactive web mapping application. Previously we stated that limitations to ES mapping have predominantly been due to the complexity of what needs to be mapped and how to map it to derive meaningful information for decision making. Moreover, the majority, if not all, of the already currently produced ES maps have been static. Past research suggests the increasing use of interactive tools in web mapping will give way to more insights for use of the ES maps in decision making (Rühringer, 2018). Interactive web mapping in recent decades has been on the rise driven by the rise in technology trends that offer more robust functionalities. Here we explore interactive web mapping and geo-visualization principles that can help guide the choices and steps in building a web mapping tool for MES.

2.2.1. Static and Interactive Web Mapping

Static maps are those maps created in digital GIS software and shared as a static format such as an image or pdf document. In static web mapping, a web map is realized through a HTML image, clickable images, and hyperlinks. There are many available definitions of web mapping and this has evolved driven by trends or eras in technology. Web mapping began with the invention of the World Wide Web which allowed for the dissemination of maps (Donohue, 2014). In this research we can consider some currently accepted definitions that describe web mapping as "the process of designing, implementing, generating and delivering maps on the World Wide Web" as defined by Neumann (Veenendaal, Brovelli, & Li, 2017, p. 2) or the technique of utilizing maps that are obtained by an information system for spatial and geographical data. Nonetheless, the core of web mapping has the 3 main components being geoinformation and their visualization(maps), geospatial software and the world wide web and it may simply be considered as a website with mapping capability. Veenendaal et al., (2017) describes that in the beginning web mapping was characteristically identified as the equivalent of having a static map published on the internet i.e. static web mapping. With modern technology "intelligent web mapping" has been adopted where a fundamental role is in the interaction between geographic information and users with exploratory capabilities. The web is a key component, and in terms of development, we currently acknowledge 4 generations of Web 1.0 to Web 4.0 (Veenendaal et al., 2017).

The foundations for web mapping development has been made possible through a number of distinct yet interconnected web development eras or stages (Veenendaal et al., 2017). The early web mapping era or static web mapping era refers to the stage of static map publishing where static maps were embedded in Hyper Text Mark-up Language (HTML) files with access via a hyperlink. This was made possible by the first-generation of the web which is Web 1.0 where the basics of Hypertext Transfer Protocol (HTTP) and HTML were implemented to show online linked information (Veenendaal et al., 2017). Then followed the dynamic web mapping era which allowed multiple users to share web maps and allowed the creation of Dynamic HTML, Common Gateway Interface (CGI), ActiveX technologies, and Java applets and servlets enabling dynamic retrieval of the maps. They provided a measure of interaction with maps. This paved way to increasing user interactions and it was followed by the services web mapping era where the development of many maps led to map servers and service-oriented architecture (Veenendaal et al., 2017). The Interactive Web mapping era where the technological solution was aimed at providing user-client interaction simultaneously with client-server interaction hence allows us today to create interactive web mapping applications.

In this research, I use the term **interactive map** to broadly capture the plethora of web maps, map-based applications, and GIS or other visualization tools that would make use of a digital map as the interface for geographic information and that can be manipulated as described (Roth, Ross, & MacEachren, 2015). **Web cartography** has been described as the "conceptual and theoretical aspects of cartographic design which includes the usability of the application along with the cognitive ability to mapmaking in a digital distributed environment" (Donohue, 2014, p. 9). In retrospect, therefore, web mapping is encompassed within web cartography where it includes the technical aspects of designing, deploying, and using maps through the web (Donohue, 2014). **Cartographic interaction** describes the "dialogue between human and a map mediated through a computing device" and the cartographic interface is "the set of digital tools through which the interaction occurs" (Donohue, 2014, p. 9). Interactive maps are ubiquitous in modern society however they may fail to work or serve their use purpose and as a result, scholars suggest the use of a User-centred Design process in the ideation, design, and implementation of an interactive web map (Roth et al., 2015).

Information visualization and in this case **geographic visualization** is a key part of the interactive web mapping applications. Geographic visualization (geo-visualization) is defined as "the process for leveraging data resources to meet scientific and societal needs and a research field that develops visual methods and tools to support a wide array of geospatial data applications"(Rhyne et al., 2004, p. 13). The term itself was prompted by a 1987 National Science Foundation report on visualization in scientific computing (Rhyne et al., 2004). The four primary functions of visualization are described by Rhyne et al., (2004) as: 'exploration' of datasets, 'analysis' of the patterns and relationship between data, the 'synthesis' in the generation of an overview and understanding of inherent information and lastly the 'presentation' of the findings. Several discussions and arguments on the meaning of geo-visualization exist, nonetheless, in this research, I simply consider the argument borrowed from (Smith, Hillier, Otto, & Geilhausen, 2013, p. 303) to be as a long-developed visual communication of cartography with current digital analytical technologies mainly being GIS. The functions of the geo-visualization are seen in Figure 6 where the focus of many interactive web maps today supports functions at the lower-left corner as compared to tradition cartography that focused on the presentation of existing information to the public (Rhyne et al., 2004; M. . Smith et al., 2013).

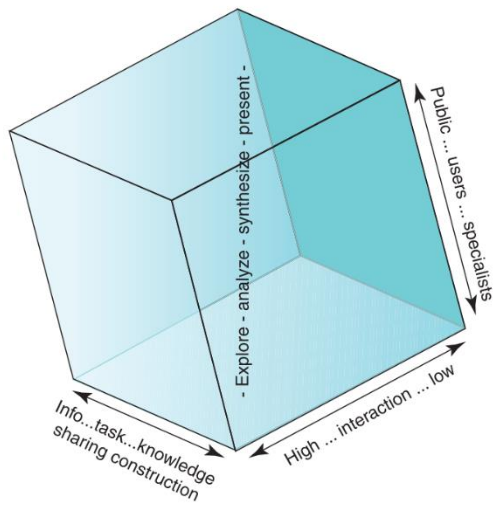


Figure 6: The Four functions of geo-visualization modified from (Smith, Hillier, Otto, & Geilhausen, 2013)

Traditionally paper maps capture the communication message conveyed by the mapmaker to a map user and this cannot be objective because it is based on the understanding and insights of the mapmaker. The goal is to transfer the geographic insights from map-maker to the user, however, it is not always the case that the message is successfully transferred. Providing interactivity means the map reader is no longer a passive component in the creation of the representation (Roth et al., 2017). Roth et al., (2017) further argue that digital interactivity looks at re-envisioning the map reader to be the map user to address the cognitive, perceptual, and practical as well as cultural influence the user's experience with interactive visualizations (Roth et al., 2017). Interactive maps, therefore, provide some advantages over the use of static maps. Furthermore, a digital environment affords a wider array of interactions and affordances for manipulating a cartographic representation, that a static analogue or paper maps could not provide (Roth, 2013).

Interactivity means the map user is empowered to switch between or create representations that best support their need or use context. Compared to static maps interactivity will allow the user to switch between views, change scales, view linkages between data and relationships, toggle information they want to see on and off and retrieve further semantic attribute or details that would not be possible with a simple static map(Roth et al., 2017). Digital interactivity has been proven in research to offer many benefits, however, as interactive maps continue to become more and more pervasive in society, driven by technology trends, the scholarly community still has questions that should be answered such as what makes an interactive visualization work and how can we ensure it meets the needs of the end-user (Roth et al., 2017). Therefore, there is an increasing emphasis on employing a UCD design approach to the entire application creation process. Beyond choosing the right approach, the appropriate visualization charts and maps should also be chosen based on careful design guidelines and principles.

2.2.2. Design Thinking and Information Visualization

Information visualization is defined as "the process of representing data in a visual and meaningful way so that a user can better understand it" (Interaction Design Foundation, n.d.-b). It draws from the fields of cognitive science, human-computer interaction, and visual design. The process of creating a visualization typically starts with first understanding the needs of the target user. Maps allow people to think visually to generate new previously unknown insights. DiBiase (1990) compares visual thinking and communication in his reproduce swoopy diagram where in the early stages of science many map solutions were needed to promote visual thinking. Science has evolved over time with the implementation of new technologies and the advent of interactive maps, therefore, in the later stages of science, a single optimal solution is needed for communication as shown in the diagram adapted by (Roth, 2013) in Figure 7.

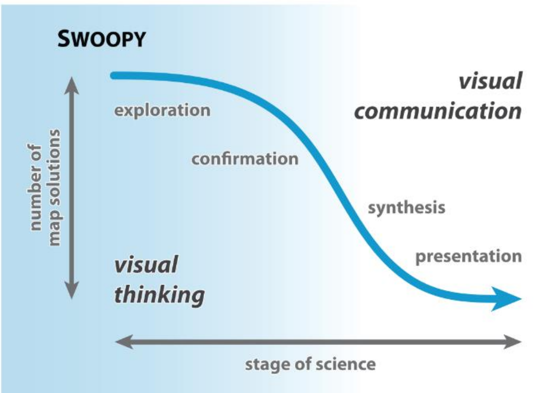


Figure 7: Swoopy diagram reinterpreted and annotated from DiBiase (1990) adapted by Roth,(2013)

To achieve usable effective visual thinking and communication, the design process should follow guidelines and best practices. Design thinking is a process that involves defining the problem, ideation, prototyping, and testing (Smith, 2018). The process is iterative and cyclic and allows for one to create a cognitive system with cost-benefit trade-offs. The cognitive aspects of an information task are described by the time and effort to learn the system, load on the user's working memory, the effort needed for comparison, and the effort needed for context switching (Baldonado, Woodruff, & Kuchinsky, 2000). These are important to consider for any system and therefore design principles and guidelines have been provided by the researcher to make it easier to achieve. Similarly, Norman (1988) suggests that a usable design should incorporate four main principles (Delikostidis, 2011):

- It should be easy to determine actions at any moment.
- Make things visible, including alternate actions and results.
- It should make it easy to evaluate the current state of the system.
- Have natural mapping between the intention and actions, action, and resulting effect and between information that is visible and interpretation.

Design Guidelines, Principles and General conventions

To guide data visualization several rules and guidelines exist. The principles that are taken into consideration and discussed in the literature include principles of visual design, Norman, (1988)'s 7 fundamental design rules, or Shneiderman's 8 golden rules of visual or interface design. Elements in visual design form the baseline of all visual graphics and they include lines, direction, colour or hue, value, texture, typography, alignment, and form (Lovett, 1999). Overarching principles (Lovett, 1999; Usability.gov, n.d.) that guide the visual design of these elements and they include:

- **Balance** – creates the perception of equal distribution of the elements, however, this does not always suggest that there is symmetry and can also be brought about by a balance of light and dark-toned shapes.
- **Unity** – refers to all elements that visually or conceptually appear to belong together. There should balance however between unity and variety to prevent overwhelming design.
- **Gestalt** aids users in perceiving an overall design as opposed to individual elements if the design element is well arranged the gestalt of the overall design becomes clear.
- **Hierarchy** is created though placement, colours, and font to show difference in significance between items.
- **Contrast** emphasizes differences in colour, size, direction, and other characteristics to make certain items stand out. It is the juxtaposition of opposing elements
- **Space** Incorporating "whit" space into a design helps reduce noise or increase readability. Space is defined when something is placed in it and is an important part of the layout.
- **Scale** identifies different ranges of sizes and demonstrates how each item is related based on their size.
- **Dominance** focuses on an element as a focal point with the other elements as subordinate and can be done through scaling or contrasting e.g. position, shape, size, or colour.
- **Repetition** with variation brings interest.
- **Gradation** of direction and size gives a linear perspective and can be used to add interest and movement or depict semantic information.
- **Similarity** – refers to continuity being created throughout a design without duplication and used to make pieces work together.

Another aspect of user interface design is providing affordances. **Affordance** refers to object properties that show possible actions users can take with the object and hence imply how the user can interact with an object e.g. change of a mouse cursor from an arrow to a pointer can indication a clickable item or colour can be used to show if a button can be pushed (Interaction Design Foundation, n.d.-a).

The above fundamentals guide the design and placement of basic elements and the next step is the general rules that guide the overall design. Norman, (1988) therefore further provides User-centred Design fundamentals where seven fundamental design rules should be applied:

i. Using knowledge in the world as well as in your head or taking advantage of convention.
ii. Creating effective visual hierarchies where you are simplifying the structure of tasks to not overload the short-term memory.
iii. Make things visible – make obvious what is clickable where the user should easily figure out the use of an object by seeing the right buttons.
iv. Get mapping right e.g. use graphics to make something more understandable
v. Exploiting the power of constraints (i.e. give the user the feeling that there is one thing to do). Referring to eliminating distractions by removing anything that does not offer a useful contribution.
vi. Design for error which means one should plan for any possible errors.
vii. Standardize. If something cannot be designed without arbitrary mapping create the international standard. (Delikostidis, 2011; Tolochko, 2016)

Usability encourages the use of heuristics (general rule of thumb) in designing as well as evaluating of interface design. Shneiderman and Plaisant (2010), provide a useful heuristic framework that is built on heuristic taxonomies specifically for web interface design known as the Eight Golden Rules of interface design in Table 1 below (Tolochko, 2016) where this research will employ most rules excluding 6.

Table 1: Eight Golden Rules of interface design by Shneiderman and Plaisant (2010)

Rule	Description
1. Strive for consistency	Meaning that it should have a cohesive experience and look throughout including the layout, colours, fonts, and terminologies.
2. Cater to universal usability	The interface should also be adaptable for different types of users such as beginners or experts including age, technical knowledge among other differences.
3. Offer informative feedback	This is when an action is completed the system should provide a response to acknowledge the result of the interaction.
4. Design dialogs to yield closure	Action sequence needs to be clear to inform the user when action is complete
5. Prevent errors	Users should not be able to commit major errors or they should be reversible or have a simple solution.
6. Permit reversal action	Should allow for action to be undone.
7. Support internal locus of control	Users need to feel they have control of the interface
8. Reduce short-term memory load	The interface should not force users to remember large amounts of information.

Web Interface Design

In web interface design and implementation, various ontologies or concepts exist such as information architecture, interaction design, and user interface, and user experience. The purpose of an interface is to present information to the users. **Information Architecture** is thus a commonly used term to organize data and it focuses on how data is structured from the perspective of the user as opposed to the system or technical perspective (UXmatters, 2012). In an interactive system, another common terminology is **Interaction design** which concerns the controls, process, and mechanisms that a user needs to perform a task using a system to meet their goals. While Visual design focuses on the aesthetics of the user interface, how it looks, and communicates (UXmatters, 2012). Most recent influences on user studies in interactive cartography relate to human-computer interaction (HCI) and usability engineering (UE) (Roth et al., 2017). While HCI looks mainly on the basic science in user interface (UI) design**,** UE employs user studies in the evaluation and improvement of a single interface. Usability Engineering is primarily the planning, and execution of usability testing to know how well people interact with the user interface (UXmatters, 2012). This is discussed further in the UCD process in 2.4.1. A lot of the previously mentioned guidelines would focus on the information presentation of the view at first glance (user interface) however it is also important to consider how the user interacts with the application that is the user experience design.

User interface (UI) can be defined as the process of making interfaces where the focus is on looks or aesthetics in a software of computer device where the aim is for users to find it easy to use and pleasurable. It typically refers to the graphical user interfaces (Interaction Design Foundation, n.d.-c). **User Experience (UX)** has been defined by The User Experience Professionals Association as "every aspect of the user's interaction with the product or service that make up the perception of the whole" (Baxter, Courage, & Caine, 2015, p. 1). It is concerned with how the user interacts with the product and consists of all the elements that together make the interface including the visual design, layout, and interaction (Baxter et al., 2015).

Garrett, (2000) focuses on the elements of user experience for web interfaces and talks about the web as a basic duality where it was originally conceived as a hypertextual information space but a rise in sophisticated technologies allows it to foster as a remote software interface. The focus here is on its use as a software interface to achieve certain tasks or analysis. In respect to this he provides several concepts in a hierarchical order based on 5 strategic planes, the surface plane which is what is seen on the surface as a series of web pages, skeleton plane referring to the placement of items such as buttons, a block of texts, structure plane which would define how a user got to a page or a more abstract expression of the skeleton, scope refers to the various features and functions and how they fit together while strategy fundamentally determines the scope i.e. incorporates the user (Garrett, 2000). Under each plane Garrett, (2000) provides a conceptual framework on the user experience with elements under each plane as in Figure 8.

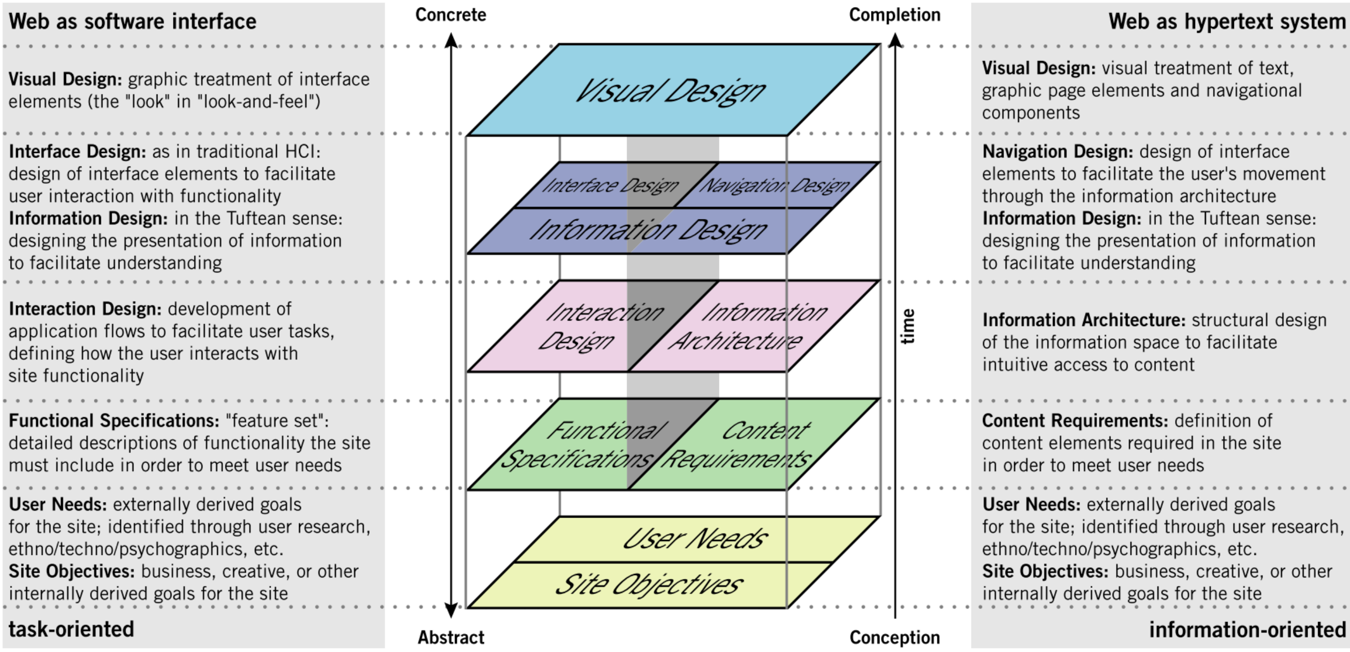


Figure 8: Elements of User Experience based on basic duality for software and system by Garrett (2000)

To ensure an interactive web application meets the user experience, Morville, (2004)created the User Experience Honeycomb which explains each facet of how to achieve user experience. They include: A product should be Useful, Usable or allowing ease of use, Desirable to the user, Findable where we should strive for a design that is navigable, Accessible referring to it being accessible for use by all users that are beginners, experts or with disability, Credible meaning that users trust and believe in the product and Valuable to the user meaning that it either increases benefits/profits or reduces friction in the previous functions of the user (Morville, 2004).

Tasks and Taxonomies of Information Visualization

To support the design and implementation of representations for origin-destination data, taxonomies for visualization help formulate the questions that can be asked and solved by the users.

Shneiderman's Visual Information Seeking Mantra: Many design guidelines exist but the basic principle is that which is proposed by Shneiderman, (1996) on visual information seeking mantra which is *"Overview first, zoom and filter, then details-on-demands"*. Shneiderman, (1996)proposes a type by task taxonomy (TTT) of information visualization where it is assumed that the user is viewing the collection of items of 7 data types (1, 2, 3 - dimensional, temporal, and multi-dimensional data). At a high level of abstraction, the seven tasks of the information-seeking mantra include overview, zoom, filter, detail-on-demand, relate, history and extract, as shown in Table 2 (Shneiderman, 1996).

Table 2: Shneiderman's Type by Task Taxonomy (Shneiderman, 1996)

Tasks	Description
Overview	Overview of the entire collection Strategies may include zoomed out views of data to see the entire collection.
Zoom	Zoom in on items of interest. Users may have an interest in a portion or collection of data or area and thus tools to control the zoom focus should be implemented.
Filter	Filter out uninteresting items. Users can quickly focus on their items of interest by allowing control over the content. Can be implemented by use of dynamic queries through sliders, buttons, control widgets
Details-on-demand	Selecting an item or group of items and get details when needed. Details of an item or group are provided when needed through selection by e.g. clicking to show pop-up or mouse hover to reveal tooltip.
Relate	View relationships among items. Cascading related effect where users can select an item, and these reveal new information or related data.
History	Keep a history of actions, support undo, replay, and progressive refinement.
Extract	Extraction of sub-collection and query parameters. Once users have obtained an item, they should be able to extract set and save.

Bertin's reading levels: A general approach for task systemization has also been proposed by Bertin, (1983) where he argues that numerous types of questions can be asked about data and for this reason, each question should correspond to a structural component of the data under analysis and therefore encompassing questions concerning all these aspects of the data (Boyandin, 2013). The basis of task taxonomy is that it is systematically derived from the data hence the visualization will better represent the analysed data. Three reading levels are therefore used to categories these questions:

- **Elementary**: Questions about a single item
- **Intermediate**: Questions concerning a group of items
- **Overall**: Questions about all elements together.

Maleki, (2016) further extends this and creates a relationship between Bertin's reading levels and Shneiderman's Visual Information-Seeking mantra demonstrated in Figure 9. Overall level seeks to have an overview of the entire collection, elementary level questions being related to details-on-demand, and intermediate level related to zoom and filter.

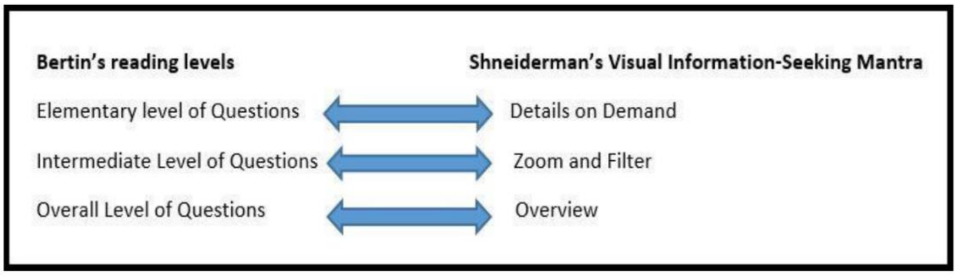


Figure 9: Bertin's Reading levels and Visual Information seeking Mantra by Shneiderman (Bertin, 1983; Maleki, 2016)

2.2.3. Cartographic Principles and Conventions

Cartographic communication is described by the sentence "How do I say what to whom, and is it effective?" (Alkema, Bijker, Sharif, Vekerdy, & Verhoef, 2013, p. 357). This process guides cartographic visualization to guarantee that the resulting map is useful to the end-user. The process entails firstly answering what information that should be mapped, then the cartographer can then choose appropriate representations and symbols to produce a map for which the user retrieves information. It is the case that often the information derived by the map user is not always the same as the information conveyed by a cartographer in the beginning (Alkema et al., 2013). This could be due to various reasons and to ensure the information retrieved is close to that communicated then approaches such as cartographic conventions and principles have been aimed at closing this gap.

Cartographic convention and best practices are drawn upon from other disciplines mainly information thinking and design as well psychology hence it entails understanding the user's perspective and following guidelines of visual design. (Turchenko, 2018)presents cartographic design principles based on five guidelines by Tyner (1992). These guidelines are map order, balance, contrast, and unity and can be likened to guidelines of visual design. These are further extended to include clarity, legibility, visual and figure-ground contrast, and hierarchical organisation (Turchenko, 2018). She hence offers a summary of cartographic principles and possible implementations. Table 3 presents the most important for the cartographic interface here as derived from previously discussed visual design guidelines.

Table 3: Cartographic principles and possible techniques (Turchenko, 2018)

Cartographic Principle	Aim	Possible techniques
Hierarchical order	-Logical coherent arrangements of elements	- Order content in different classes - Order within one class using sizing - Subdivision within one class
Balance	- The visual centre is considered above the actual centre of the map - To coordinate the graphic and visual weight of map elements. - The map should have the largest possible scale to avoid the predominance of unfilled white space.	- Graphic weight could be based on color tones being darker or lighter. - Visual weight depends on the arrangement as well as the size of the map elements. E.g. elements in the upper right corner have more weight than in the lower-left corner, or separate elements are heavier than grouped.
Legibility(clarity)	- To emphasize importance - Eliminate what is unnecessary - Ensure the legibility of map symbols and the readability of labels.	-Appropriate associate map symbol and size of symbols - Readable typefaces -Label placement should be efficient.

Visual contrast	- Contrast between map elements - Draw user's attention to relevant map elements - Avoid visual monotony	- Use of contrast such as light and dark, thin, and thick. - Differences in size intensity colour or shape.
Figure-ground contrast	- To emphasize the relevance of figure (main map content) and foreground (rest of space)	- Differentiate detail levels - Drop shadows - Size of symbols - The difference in colour value - Multiple views
Unity	- To provide visual perception of a map as a single visualization	- Harmonize interrelation of all map elements e.g. colours, fonts used.

Cartographic Representation Design

To map any information the first step entails understanding the nature of the data and the type of scale. Data may be qualitative data or quantitative data. Qualitative data is discrete and has no order it refers to distinct entities and is also referred to as nominal or categorical data. Quantitative data is measured data either along an interval scale which has no absolute zero scales such as temperature or ratio scale which has an absolute 0 such as income (Alkema et al., 2013). The four levels of measurement scale are described in Table 4.

Table 4:Measurement of scale and nature of data (Alkema et al., 2013)

Measurement scale	Nature of data
Nominal, categorical	Identity of things/ different nature (qualitative)
Ordinal	Data with an order but not quantitatively ordered.
Interval	Quantitative without absolute zero
Ratio	Quantitative with absolute zero

In cartographic representation after determining the data type, we define the main or most basic elements that constitute the map which is visual variables. Visual variables have been provided by scholars as the basic elements regardless of the medium used to communicate and they are derived from the basic visual elements such as line, point, and area symbols. Bertin, (1967) distinguishes 6 variables including size, shape, orientation, colour hue, value, and texture, and may also include location (Alkema et al., 2013; Turchenko, 2018). This has been extended to include saturation and arrangement and crispness, resolution, and transparency (Turchenko, 2018). Visual variables influence the map user's perception which depends on the human capacity to see what is of equal importance, order, quantities, and instant overview of the mapped theme (Alkema et al., 2013). Visual variables have been categorised into four levels based on visual, perceptual, and understanding the properties of variables. *Associative level* is perceived with the same level of significance, *selective level* is where the human eye can distinguish one variable from another, *ordered level* allows sequential ranking of variables between opposite states (Turchenko, 2018). The quantitative level can provide an understanding of numerical values of data. The summary of visual variables and their associated use in different categories of visualizing data are summarised by Roth, (2017) in Figure 10.

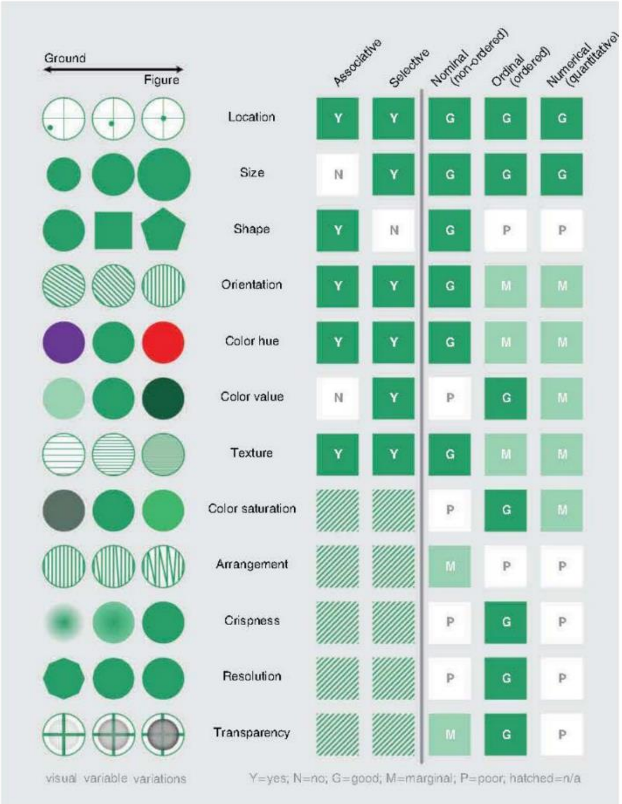


Figure 10: Visual variables presented by Roth, (2017) with respect to organizational levels

Cartography design principles are based on the manipulation of map elements to provide meaningful representation. Turchenko, (2018) describes these elements of cartography and their characteristics and argues that these elements can belong to different visual levels or can be placed in vertical visual hierarchical organisation levels. These elements according to their weight in a visual hierarchy are listed below based on Turchenko, (2018)'s visual hierarchy. These elements are later discussed with possible adaptation for the web in designing the web application.

1. Figure, subject area (mapped area) - Should be centre of the map and first in the map element hierarchy
2. Title and subtitle – describe the content. The title should draw more attention of the user than subtitle (emphasis).
3. Map Legend – the labels should be consistent with the map topic and its content should explain the map symbolization.
4. Map Scale – Can be represented as a scale bar, representative, or relative fraction or labelled graticule.
5. Orientation – The north arrow can be used when the map is not facing north, or graticules could also determine orientation.
6. Border and Neatline – provide separation of map content from surround to help bring content into focus.
7. Names and Labels – should be legible and font size should correspond with feature weight.
8. Credits – can include the author, license, date, and data source.

9. Grid/Graticule – helps identify location coordinates using parallels and meridians.
10. Map symbols – are the main elements of a map to represent thematic/geographic information.

Map composition and layout is also of importance in the cartographic representation. According to Tolochko, (2016) *map composition* refers to visual hierarchy or decision to emphasize on specific map elements while *map layout* refers to the placement of these map elements and non-map elements (Muehlenhaus, 2013; Tolochko, 2016). Table 5 shows a suggested map composition adapted for the web from (Muehlenhaus, 2013). These are further explored in chapter 4 in the design stage.

Table 5: Suggested map composition, as adapted for the web. Adapted from Muehlenhaus, (2013)

Visual Hierarchy Level	General Interest Web Maps	Thematic Web Maps
Level 1	Title, subtitle/splash screen Map symbology Reference data Information windows	Title/splash screen Thematic visualization Legends
Level 2	Base map Navigation tool	Base map Information window Supplementary graphs
Level 3	Map interactivity	Base map labels Map interactivity
Level 4	Locator maps Supplement graphs	Locator maps Supplement graphics
Level 5	Metadata Tooltips	Metadata Tooltips

Cartographic Interaction Design

Interaction design is that which allows users to do the “right” thing at the “right” time. How the user says something e.g., clicks and how the map responds e.g., increases zoom level. To understand cartographic interaction, design the basic principles of UI/UX design are adopted such as in any digital component (Tolochko, 2016). A cartographic interface is a digital interface that allows the user to interact with the map and can include direct manipulation of the map itself. Cartographic interaction primitives are the fundamental components of interaction and are combined to characterize a complete interaction sequence. To support the design of web maps, scholars have developed a taxonomy of cartographic interaction primitives (Roth, 2013; Tolochko, 2016):

- *Objective-based* – the goal of a user in using the map e.g. identify, compare, locate, distinguish, categorize, rank, explore, filter, emphasize, extract.
- *Operator-based* -functionality that is available to interact with the map to fulfill user objectives e.g. highlight, label, linking, overview, zoom, filter, details-on-demand, extract, toggling visibility, etc.
- *Operand-based* – part of the cartographic interface that the user interacts with e.g. data and data representation, view, time, location, object, visualization structure.

Other common interaction techniques adopted by scholars include details-on demand, manipulating views, linking, and brushing, zooming, and direct manipulation as discussed by (Butz, n.d.). *Details-on-demand* provides improved scalability where displaying information about data is based on the demand of users e.g., hover and tooltips. *Manipulating views* is an interaction technique that refers to moving view position or changing representations in a view. *Linking* refers to the connection between multiple views of the same data space where updating one updates the other. *Brushing* can be related to linking where an interactive interface tool selects or masks data and with linked views can support correlation. Brushing is usually used to visually filter data such as highlighting. *Zooming* and panning are other interaction techniques where the scale and translation may either result in a geometrical zoom i.e. shape and size or a semantic zooming i.e. change in attribute data information (Butz, n.d.). It is important to note that some rules apply to these interactions such as the rules discussed by (Baldonado et al., 2000)on when and how to use multiple views. In general, a lot of cartographic interactions are available in a digital environment to be used, however, the choice of what to use and why is determined in the UCD process by the user's needs or requirements and hence resulting functionalities chosen (section 4.1.2).

2.2.4. Origin-Destination Data and Representation

The careful selection of map type or visualization charts is dependent on the intended message and the data to be visualized. Many datasets, including the one used in this research, represent entities moving between geographic locations are produced daily and many of these are collected in form of spatial interactions known as origin-destination data, which means that the origin location, destination location of the flows and the magnitude of the flow are known, but not the exact movement or route was taken (Boyandin, 2013). The tuna fishery data are characteristic of this where the location of harvest, processing, and consumption are known and the weight of the resource, but the routes are taken to the end destination are not known. The unique aspect of this case is that it does not simply have one origin and destination but has intermediary locations or what may be referred to as branching origin-destination data. For this reason, the choice of representation has to clearly show the demarcation of flows moving from one origin to intermediary destination and this intermediary location to a final destination. Such data remains largely unused or unreleased and their full potential is not utilized because the techniques and tools to support their exploration, as well as visualization, is yet to be developed (Boyandin, 2013). Boyandin, (2013) defines origin-destination data as a collection of flows of entities between geographic locations, where each flow is characterized by the following features:

i) Origin – a geographic location
ii) Destination – geographic location
iii) Magnitude – numeric value to characterise the amount of entities flowing (e.g. metric Tons, dollar value)
iv) Type- nominal value that describes the entities flowing (e.g. tuna fish catch, tuna fish processed)
v) Time - a precise date/period the flow was measured

OD data mapping and visualization have become important due to the significant amount of data produced that is characteristic of this type of data. Such datasets may include flows of people, food, animal, money, material, network traffic between pairs, among others. Examples of datasets that exist and have been mapped in the literature include the flow of internally displaced refugees in Afghanistan and Iraq where a flow map representation was used to capture this information (Boyandin, 2013). Another example is the flowstrates interactive application created by (Boyandin et al., 2011)to visualize the flow of refugees between East Africa and Western Europe where two types of visualizations are used for representation including an OD-matrix and two related flow maps. Here Boyandin et al. (2011) were able to depict the flows origin and destination and changes of the magnitude over time in Figure 11.

Figure 11: Flows of refugees are shown between East Africa and Western Europe by Boyandin et al., (2011)

Map distortions have also been used to represent OD data and bring meaning out of origins and destination. An example is that of Stefaner (2010) who visualizes outgoing and incoming migration to and from New York where a symbol map is used (Boyandin, 2013). The country centroids are repositioned to avoid overlap and since most origin and destinations are within New York the city is enlarged while the rest of the world is distorted (Figure 12).

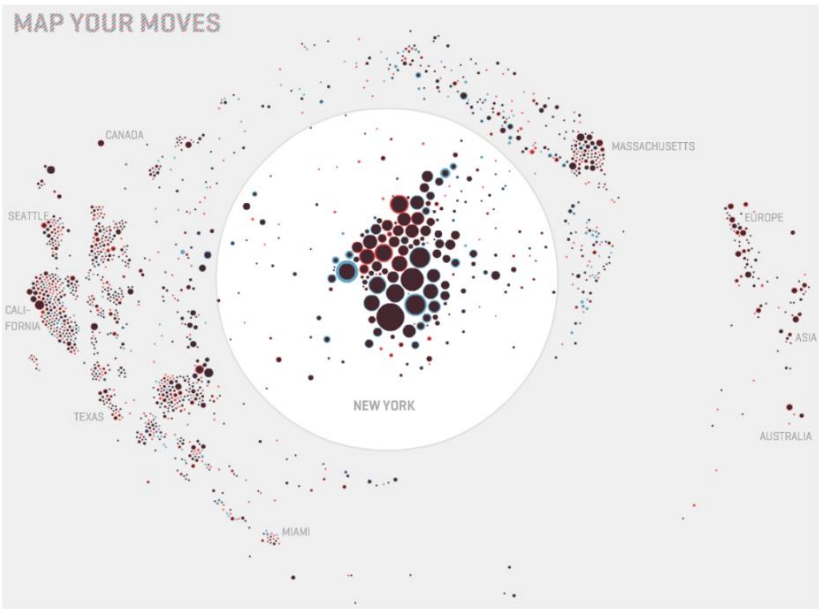


Figure 12: Online interactive geographic symbol map of outgoing and incoming migrations to and from New York by Stefaner (2010) where the world map is distorted (Boyadin, 2013)

OD Data Representations

The aim of any cartographic product is to find the most suitable way of representing such data in a way that effectively assists the end-user to explore, analyse, and answer questions. These are defined as user tasks and suitable representation of OD data should allow achieving tasks such as:

- Find the origin and destination of flows and determine their direction
- Examine the overview (big picture) of entire dataset or focus on a region and determine patterns
- Compare flows between different OD pairs
- Find the largest and smallest magnitude of flows (Boyandin, 2013)

To address these, one of the most common representations of OD data is flow maps. *Flow maps* are a visualization that represents entities flowing between geographic locations on a map which is overlain with connecting lines from origin to destination. Flow maps help answer what are the largest and smallest flows, where are origins and destination, which is the direction of the flow. Geographic flows or flow maps only show cumulative movements that took place at a time-period but can be extended to animated flows that show time (Boyandin, 2013). Flow mapping is the choice of representation and guidelines in flow mapping are discussed briefly in the subsection below.

Boyandin, (2013) discusses some examples of other design alternatives of visualization that exist in literature. The *OD-matrix* is one such example where flow magnitudes are represented by cell colours in a heatmap with rows corresponding to origins and columns to destinations as in Figure 13 (Boyandin, 2013). OD-maps is another geographic approach by Wood et al., (2010) where the map is divided into a regular grid as a small replica of the whole map, with the idea of nesting employed further from OD treemap (Boyandin, 2013).

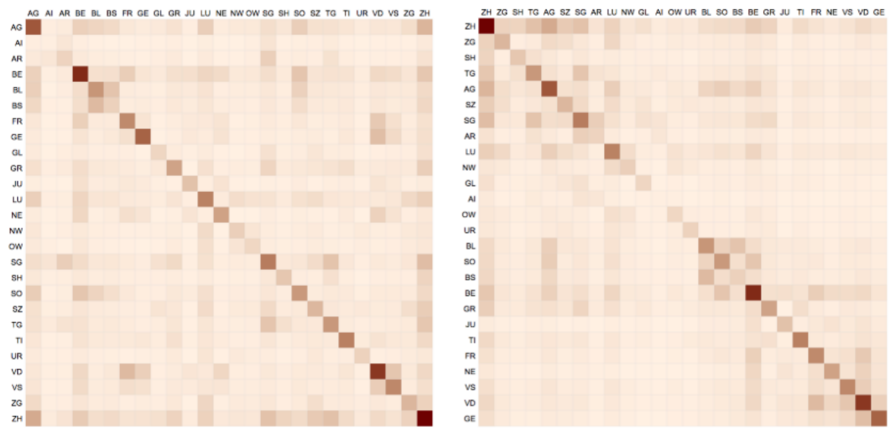


Figure 13: Example of OD-matrix showing migration between cantons in Switzerland where left diagram orders row and column alphabetically and right orders by distance to canton centroid.(Boyandin, 2013)

Other representations include the *Sankey diagram* which uses lines and nodes in horizontal layout to show flow and magnitude is expressed by the thickness of the line. *Chord diagrams* are like Sankey diagrams where they use a radial layout of representing locations and flows are shown as lines with varying widths connected between nodes. *Arc diagrams* are also used to represent od data where nodes are placed in a straight line and connected via circular arcs with varying thickness of arcs. A modification of arc diagram is the *Sankey arcs* that combine both Sankey and arc characteristics where instead of drawing all arcs from the node-centres, their ends are placed adjacent to each other see Figure 14 (Boyandin, 2013). There several other representation techniques that may not have been discussed e.g. OD-tree maps, OD-maps, Hive plot, Symbol maps (Figure 15), and Origin and Destination symbol maps, among others in literature (Boyandin, 2013; Jenny et al., 2018). This research however explores the use of flow maps along with other supplementary visualization such as Sankey diagrams and charts along with multiple views to aid in the understanding of the data. Multiple views and visualizations have been observed to offer advantages such as improved user performance and the discovery of unforeseen relationships (Baldonado et al., 2000).

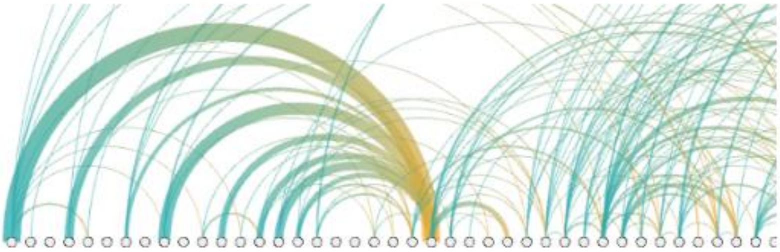


Figure 14: Part of arc diagram showing rides between bus tops in Singapore where colour gradient depicts flow direction (Boyandin, 2013) image by the courtesy of Till Nagel

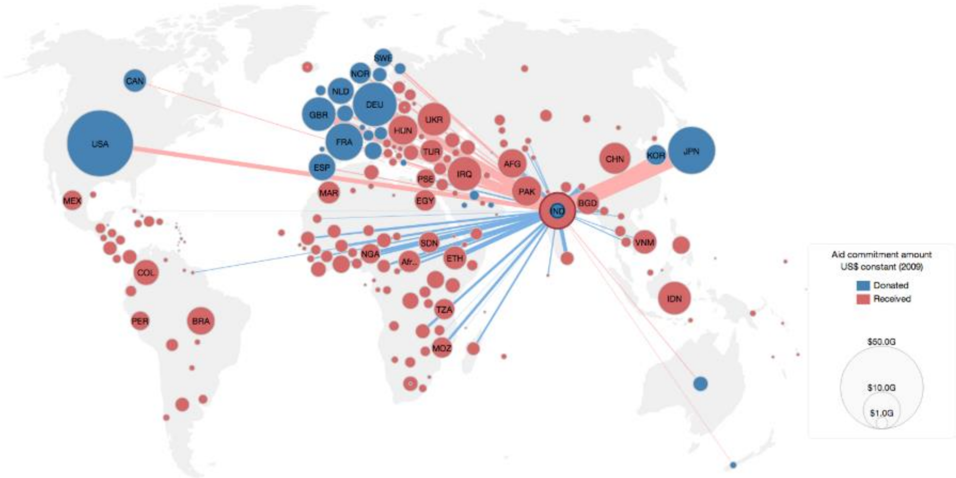


Figure 15: Example of a flow symbol map using varying sizes to represent magnitude of incoming and outgoing flows of financial aid countries (Boyandin, 2013)

Boyandin,(2013) also discussed the need to consider the different aspects of OD-data representation and classify the visualization techniques according to these. The aspects of classification are tied with the analysis tasks and taxonomy as well. In the classification of OD data representation techniques, the following aspects are suggested:

- Layout (how nodes representing locations are laid out on screen)
- OD (the way in which origin and destinations are positioned)
- Flow (how flows between origin and destination are represented)
- How direction is represented
- How magnitude is represented
- Distance between origin and destination representation if necessary
- OD total (outgoing and incoming totals)
- OD degree (if the number of outgoing and incoming flows of each node are represented) (Boyandin, 2013)

Beyond the classifications specified by Boyandin, (2013) in this research it is also important to distinguish the intermediary destination points as the MES flows are represented as data that has more than one destination i.e. multiple origins and destinations e.g. differentiation between the harvest location as origin, the processing location as an intermediary location and the market as the final destination. Therefore another classification is the OD step which refers to how to represent the data at each step of the flow to discern or differentiate between origin to destination flows of the first step in a supply chain and origin to destination flows of the second or third steps in the supply chain.

Flow Mapping

I chose to focus on the use of flow maps as the main visualization to communicate the flows of MES along with supplementary visualizations including bar chart, Sankey diagram, and choropleth maps, I, therefore, further elaborate on those in this chapter. A flow map is the most often used representation of these kinds of spatial interactions. The flows are represented as lines or arrows that are drawn to connect the origin and destination on a geographic map. The goal of this representation is in finding answers to questions as discussed previously such as what are the largest flows, the direction of flows, or where are the origins and destinations?

The first known flow maps were created by Henry Harness in 1837 to show the relative number of travellers conveyed in different directions through Ireland for the Railway Commissioners (Boyandin, 2013). From here between 1845 and 1869 Charles Minard, produced numerous flow maps and made the technique popular. One famous chart by Minard is that which showed the decline of the size of Napoleon's army in the Russian Campaign and another is that which Minard created to show the migration of people between the world countries (Tufte, 1986). The first computer that could display a flow map was developed in the late 1950s. A renowned cartographer, Waldo Tobler, not only created the software for basic flow mapping but also investigated approaches to make the flow maps more readable (Boyandin, 2013). This mapping technique grew in popularity ever since and most recently researchers investigate and provide best practices to make these visualizations more readable and easier to understand. Flow maps are a complex type of map representation in which researchers such as (Jenny et al., 2018) have provided various principles and best practices, and these techniques are well elaborated by (Boyandin, 2013).

Principles of Visualizing Flow Maps

Representing **directionality** of flows is important to understand the origin to destination of an entity or in which way the entity is moving. Direction can be shown in many ways such as using arrows pointing to the direction of movement, varying the hue, intensity, or transparency of flow line colour, varying thickness, or bending the flow line in a recognizable way. Figure 16 shows an example of the use of tapered edges for representing flow direction which is said to reduce clutter compared to the conventional approach of using arrows (Boyandin, 2013; Jenny et al., 2018). However, the limitation is that because of the tapered shape of the arrows, it becomes harder to read the magnitude of flows. Another limitation is that the representations can make it difficult to perceive direction and magnitude for very thin and curved lines. The use of hue and intensity is also a great way to perceive direction with the limitation of having colour additive where flows interact and overlap (Boyandin, 2013). A recently adopted interactive method that proves to be effective is embedding animated moving patterns into each of the flow lines where due to animation many limitations are eliminated such as clutter caused by the use of arrows, overlaps using hue, hard to perceive thin flows using tapered flows among others (Boyandin, 2013). Hence animated flow lines are an effective way to perceive direction.

Figure 16: Flow Map which employed tapered edges in representation of flow direction. The map shows the number of refugees from various origins residing in other countries in 2005 (Boyandin, 2013)

Representing the **magnitude** of the flows is also important in flow maps. Techniques suggested for this have been flow line thickness which is one of the most common techniques where you vary the thickness of each flow. Flow line colours is another method of assigning different colours depending on the magnitude where a sequential monochromatic scale is best to show varying magnitude. The advantage of colour over thickness is that it avoids clutter by occupying less space, however, colour is inferior to size as a visual variable hence the human perception allows us to make much less accurate colour comparison (Boyandin, 2013). An alternative is the use of particles moving along flow lines either having varying speed or size in density. Studies have shown the use of short line segments moving along flow lines are best to represent flow direction not for conveying magnitude (Boyandin, 2013).

Another key issue related to flows is the representation of **bi-directional flows** which represents flows between the same two nodes in opposite directions. The two flows have their own magnitude which should be perceived hence Tobler describes a solution that suggests putting smaller arrows on top or larger and using half-barbed arrows. However, he states that these approaches are not very effective visually. A representation by Bahoken (2011) describes a minimal overlap and clutter technique as seen in Figure 17. The first two approaches are most often used, and their relative effectiveness can be speculated despite not much research has been done on this (Boyandin, 2013).

Figure 17: Representation of bidirectionality by Bahoken, (2011)

Other than bi-directional flows another design concern especially with visualizing data such as MES flows is the case of **self-loops**. It is often the case that OD-datasets have the same origin and destination where the magnitude within the location is described these are referred to as self-loops. Literature suggests the use of alternatives such as circles, rings, donuts, or other kinds of looping arrows see Figure 18. An effective flow map should provide a comparison of self-loop magnitudes to those of other flows hence consideration of how to draw them is important to avoid confusion (Boyandin, 2013).

Figure 18: Representation of self-loops in flow maps (Boyandin, 2013)

Challenges with flow maps

Flow maps have grown in popularity however they have several design challenges that require certain techniques to address. One such problem is visual clutter and occlusion. This problem is worse when trying to depict many flow lines at the same time. Another problem is that flow maps can be misleading where longer lines take more screen space and thus draw the user's attention away from shorter flows of larger magnitude. Also, locations with a lot of incoming or outgoing flows also appear to be more significant even if total magnitudes are smaller (Boyandin, 2013). An example of a cluttered map that is hard to read is seen in Figure 19.

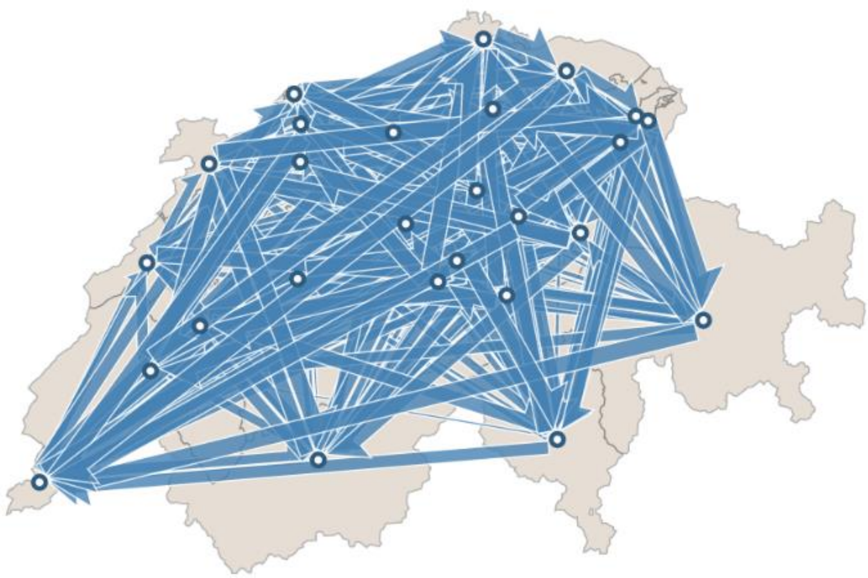


Figure 19: Cluttered map of flow lines after sorting by magnitude, larger flows are drawn above therefore visually obscures smaller flows (Bonyandin, 2013)

To address clutter Boyandin, (2013) suggests the following approaches that may be considered in this research include:

- Visual techniques that improve readability, which can include several techniques such as sorting lines by flow magnitude, showing only parts of the flow lines, shortening flow lines. However, this technique may affect the accuracy of the users in performing analysis tasks.
- Another approach is interactive filtering/ automatic sampling where the number of flows displayed at a time is reduced by keeping only the most important. The flows can then be either selected by the user based on a specific property or automatically using certain defined guidelines.
- First location totals, then flows on-demand which follows Shneiderman, (1996)'s visualization seeking mantra of overview first, zoom and filter then details-on-demand. Not all available details are thus displayed at once and the user interacts with the map to reveal the information of interest.

Other techniques that I have not discussed in-depth but exist in literature are showing only differences from expected, segmenting into flows between adjoining regions, coarsening spatial resolutions, use of Sankey flow maps, and bundling (Boyandin, 2013).

In conclusion, the aspects of design presented here are used either implicitly or explicitly in this research, where some principles are regarded to more as a general convention or how things are done while other design considerations are explained further in the method and results and choice of solution is also explained. Many researchers still emphasize the use of the above design guidelines and principles as well as the implementation of the general rule of thumbs. Furthermore, emphasis and focus is given to the user and hence the use of a User entered design approach. To implement these designs, however, specific technology and software are required and the approach to implementing the web application from design sketches or wireframes to web prototypes and applications requires a systematic process which is discussed in the following section.

2.3. Web Mapping Development Process

Web design and development while informed by Human-Computer Interaction (HCI) and User-centred design (UCD), encompass technologies and practices that involve the production as well as maintenance of websites. There is no formal discipline to this per se but an amalgam of both professional and amateur practice (Donohue, 2014). Developers will investigate development patterns and similar approaches to decide which libraries and technologies to adopt. One popular approach for building an interactive web map application is the five-stage prototypical workflow proposed by Donohue, (2014). The workflow was proposed to teach students on the steps taken when creating an interactive cartographic application and it showed that it is effective to ensure all aspects of the development process are sufficiently addressed (Donohue, 2014). This workflow encompasses full stack development which is a range of technologies and technical skills needed to create a functioning web application (Donohue, 2014; Tolochko, 2016). Full-stack development has two components: The front-end which may be referred to as client-side and the Back-end technologies or commonly called the server-side (Tolochko, 2016). Donohue, (2014)'s workflow for full-stack development starts from bottom with back-end related work which involves server configuration and establishing data models either stored as in relational spatial databases or flat text-based files such as GeoJSON, TopoJSON, csv for smaller web applications. Then follows the Application Programming Interface (API) layer which integrates data model with business logic of the application and code libraries or frameworks. Then the User Interface layer primarily uses technologies such as HTML, CSS, and JavaScript for design and interaction. This is finally aimed at achieving the user's goal.

This full-stack development informs the data-representation-interaction process for interactive web map design. A prototypical web mapping process that can be used to understand the development process is suggested by Donohue, (2014) as described in Figure 20. It encompasses understanding the development environment for which the application will be used, properly structuring directory and files within the computing system, cleaning, and restricting data to a usable encoding form (e.g. GeoJSON or TopoJSON). This is followed by a thorough understanding of the code libraries available for the implementation including learning scope on the relationship between structural elements (HTML, DOM) styling such as CSS and behavioural elements such as JavaScript (Donohue, 2014). As a best practice, the development process should be documented for each version using a code versioning system (e.g. GitHub, Bitbucket). This process is followed in the implementation of the application.

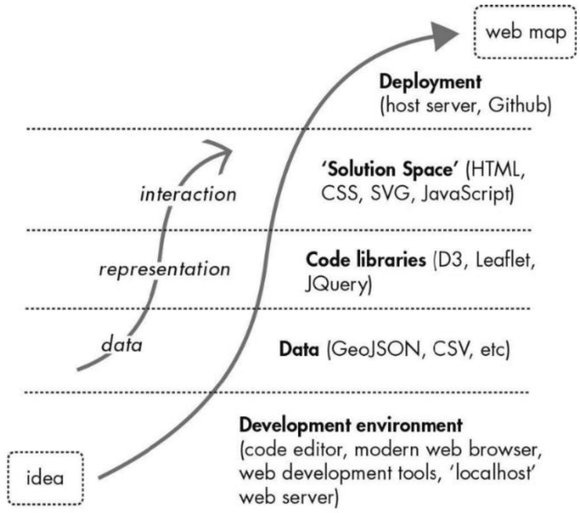


Figure 20: A prototypical web mapping workflow example by (Donohue, 2014)

In the implementation of web map application, Tsou & Curran (2008) describe three major components for progressive levels of website design and implementation. They are derived from Garrett's 5 stage framework on web application that is like ISO' standard 13407 on "Human Centred Design for Interactive Systems". The components are databases, web map servers, and browsers.

Data and databases – the first step to creating a web mapping application is the pragmatics of data acquisition, curation, and ingestion into a database or storage. Once data is reformatted the options of storage can either include the use of a database e.g. PostgreSQL or file-based system or both. Database design is usually the first stage in web map application and is driven by the type of data to be mapped. The developer identifies the scope of data required, how to acquire the data and clean, and finally how to reformat and structure the data to the appropriate format and structure that can be stored in the database. A GIS database is then designed and created, and the collected data is pushed to an integrated relational database or multiple files. GIS databases are then connected to a web map server to provide geospatial information.

Web Map Servers – the first step entails gathering information collected for determining the functional specification and formalized mapping functions. Web map servers provide different mapping functions depending on the GIS capabilities examples include Map-Server, Geoserver, ESRI's ArcIMS. Once a web map engine is chosen, considerations are decided on features and customizable functions such as buffering intersect, etc. This research uses a flat file-based system for storage hence I do not cover distributed servers in depth.

Map Browser/Front-end – these are the client-facing or visible components of the web mapping application. They cover both interface design and symbolization of the web map layer. The GIS functions and user interfaces are supported by web map servers. The user interface and user experience design of browsers are the most critical part of web mapping as the users directly interact with this hence they require a user needs approach and pragmatics of UI/UX design to be used in the implementation as previously discussed.
(Garrett, 2002; Tsou & Curran, 2008)

2.3.1. Technologies commonly used in Interactive Web Map Development

To create a web mapping application, certain prerequisites are required derived from the pedagogical model for web mapping by Donohue, (2014). The following learning objectives are key to catalogue the skills and technologies that one needs to learn and use:

- Understand browser-related frameworks such as HTML, CSS, and JavaScript and how they work together in interface design.
- Address limitations in native support of a library used in web mapping such as search and filter. Determine which is the most suitable library for the application of functional requirements.
- Understanding of the data structure and format that can be used e.g. GeoJSON, TopoJSON, CSV and how to integrate this with the DOM using JavaScript
- Know how to use web development tools for debugging and inspecting rendered DOM elements.
- Learn how to interpret examples that exist and modify code to apply different implementation solutions.

The web map of today has moved from static pages to better incorporate dynamic interactive nature of cartographic representations. Most web browsers are increasingly adopting standards that provide consistent and accessible authoring and deployment. Some of the standards that are supported are (Donohue 2014):

- Hypertext Mark-up Language (HTML) – structures a web document
- Cascading Style Sheets (CSS) – governs the aesthetics and layout of the web page.
- Scalable Vector Graphics (SVG) – text-based web standard vector graphic that describes vector shapes
- JavaScript – prototype-based server scripting language
- Web Application Programming Interfaces (APIs)
- Document Object Model (DOM) – describes entities in a web page and Canvas element which supports bitmap raster (Donohue 2014)

Today web maps are rarely written in pure JavaScript (vanilla), they are rather a mash-up of collectively authored libraries that offer foundational support for several tasks in the display, manipulation, data deserialization among others (Bostock, Ogievetsky, & Heer, 2011; Donohue, 2014). Libraries such as D3 exist to build custom interfaces by more tech-savvy authors. **D3 (Data-Driven Documents)** is an open JavaScript library that is created and maintained by Mike Bostock (http://d3js.org). Several researchers have stated the advantages of native libraries for novel solutions that require custom visualization and one very powerful library for this purpose if D3.js. Beyond technologies such as HTML, CSS, D3.js, other supporting libraries include bootstrap.js and popper.js which are useful in quick implementation of the user interface layouts and interactivity. A good code versioning system is also paramount such as the use of Git for version control and GitHub to share the code and collaborate.

In conclusion, the basics of the application development include creating the idea based on the user needs assessment, choosing the right development environment and coding libraries, acquiring cleaning and restructuring the data and storage of this data, then implementing the solution space using web technology frameworks and libraries available. The steps used in implementation are built upon these pragmatics and discussed in section 4.3 under the implementation of the cartographic interactive application. As mentioned, the first step to any design process is the user and hence the following section introduces the user-centred Design principle and the approach taken in the overall project workflow.

2.4. Use and Users of Geovisualization Products

In recent years, research involving computer-based cartography has evolved mainly motivated by the need to improve computational speed and flexibility to solve technical issues where new technologies have been applied and researchers have focused on the new possibilities for geospatial data interaction (van Elzakker & Wealands, 2007). While this technology-centred development should bring about solutions to various issues, the approach purely does not accommodate representations of the user, consequently failing to meet their goals. In recent years there has been a great emphasis on the need to focus on users of a product within many project cycles where perceptual and cognitive processes are deemed. Perception captures the map user's initial reactions while cognition deals with perception as well as thought processes, the prior experience, and memory to derive meaning from a map (van Elzakker & Wealands, 2007). Digital interactivity entails the map reader to be re-envisioned as the map user. It requires us to address perceptual-cognitive, cultural, and practical considerations in order to influence how a user experiences the information product (Roth, 2013).

It is also important to distinguish between users and uses; where *uses* refer to the related tasks, geographic questions, purposes, and application, *users* are those that actively try to understand the system, pose questions and look for answers to solutions (Alkema et al., 2013). Both uses and users play an important role in the design of a product. Traditionally the map user has always played an important role in the cartographic communication process, however, the feedback and revisions were not in real-time. In web-based mapping applications, the map user can change content immediately and visualize different map information in real-time, hence the role of the map user in the development of maps has become significantly more important in digital cartography (Tsou & Curran, 2008). Therefore, in creating a successful web map application all key components of the systems such as databases, web map servers, and map browsers need to adopt a UCD approach. This section explores the theoretical foundations of processes adopted in a user-focused approach including principles and concepts in the user-centred design cycle, usability, and user experience.

2.4.1. User-Centred Design Process

User-centred design is one of the main research areas in computer science and Human-Computer Interaction (HCI) where the emphasis has been placed on the importance of HCI, user interfaces, and user-centred design approaches (Tsou & Curran, 2008). UCD has been described as a product development approach that focuses on end-users and draws from aspects of ethnography and cognitive and experimental psychology. It is a "philosophy based on the needs and interests of the user with an emphasis on making products usable and understandable" (Tolochko, 2016, p. 1). In the 1980s the UCD framework emerged as one of the driving principles in designing usable technologies (Haklay, 2010; Lorena, 2019). Three key principles guide the UCD design process and its adaptations:

1. An early focus on understanding the user and context of use.
2. Empirical evaluation of design products by representative users.
3. Iterative cycle of design production evaluation and redesign (Baxter et al., 2015; van Elzakker & Wealands, 2007).

The first principle focuses on the systemic and structured collection of the users' experience which can help gain an understanding of what are the users want and needs, how they currently work or their context of work, and their mental representation of their domain (Baxter et al., 2015). Knowing the users, the tasks they should carry out and their use of context should be determined on the early development process. The empirical evaluation or measurement of product guides the product design and usability where users use and test the prototypes of the product early in the development phase and their performance would be measured. This should also be assessed early in the product life cycle. The iterative cycle of design recommends that experiences collected are used to repeatedly re-design and modify the product until the user is satisfied (Baxter et al., 2015).

Various authors describe different adaptations of the UCD process (Robinson, Chen, Lengerich, Meyer, & MacEachren, 2005; Tyner, 2010; van Elzakker & Wealands, 2007). According to Van Elzakker & Wealands, (2007) the UCD approach is divided into three main stages that help to obtain a satisfactory design solution (see Figure 21) and they include:

- Analysis of requirements,
- Production of design solutions and
- Evaluation of design.

The first stage identifies the users, user needs and the context of use, the production phase is related to the development of the conceptual design and the implementation of prototypes while the final stage is an evaluation by representative users. The last two stages are an iterative process that allows for improvements to satisfy the user's needs (Lorena, 2019; van Elzakker & Wealands, 2007).

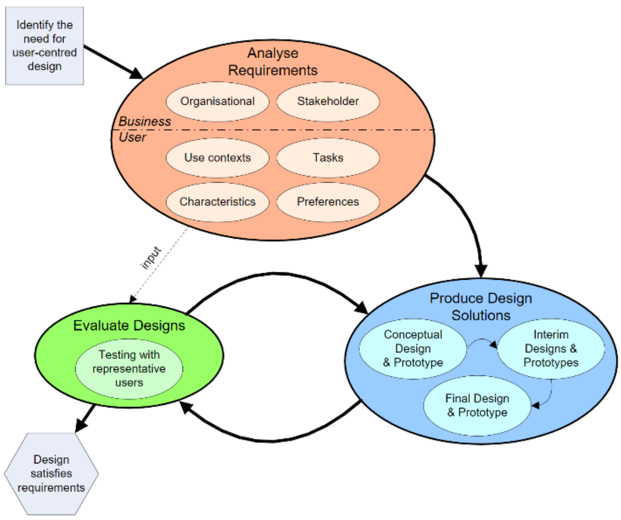


Figure 21: User-centred design (UCD) cycle (van Elzakker & Wealands, 2007)

Other authors such as Robinson et al. (2005) describe the UCD process for design in 6 stages: *Work domain analysis* which is the initial research to be mapped also referred to as the needs assessment, *Conceptual development* which is a written formalization of the requirements, *Prototyping* as a highly iterative process of the creation of prototypes, *Interaction/usability assessment* which entails evaluation of the product to receive feedback and may be formal or informal and the last two stages include *implementation* stage where changes have been incorporated to the design and finally *debugging* to ensure the stability of the interactive web map application (Robinson et al., 2005; Tolochko, 2016).

Roth et al., (2015) describe UCD for user interface guidelines as a flexible process based on the key guiding principles where an interactive map is continuously evaluated against established criteria, hence promoting subsequent modification and adaptations (Nielsen, 1992; Roth et al., 2015). Roth et al. (2015) suggest an adapted multi-stage approach that involves 10 steps based on the work of Nielsen, (1992). His work continuously focuses on the user throughout all development stages and he describes employing a UCD approach for successful implementation of interfaces. The first stages mainly centre on the user and context of use while the latter stages emphasize the importance of iterative evaluation and revision. They include:

1. Know the User – conduct a **needs assessment/task analysis** to derive user profile and use case scenarios.
2. Competitive analysis – critically compare existing interfaces designed for similar use.
3. Setting Goals- derive a requirements document with desired functionalities based on 1 and 2 to guide prototype design and development.
4. Participatory design – recruit representative target users to be involved in the conceptual interface design
5. Coordinate design- develop a consistent product identity (look and feel) through the coordination of design in the team.
6. Guidelines and heuristic analysis- recruiting experts in the design and development phase to evaluate interface according to set guidelines. *Guidelines* referring to insights from the scientific investigation of interfaces and *heuristics* referring to well-accepted overarching design principles from experience.
7. Prototyping-create static or interactive mock-ups here referring to alpha and beta releases.
8. Empirical testing – evaluate the utility and usability of prototypes with a representative sample of the target group
9. Iterative design – revise the prototype based on feedback from guideline analysis and empirical testing.
10. Feedback from field use- collect feedback from the field to inform product releases in the future (Roth et al., 2015)

The 1999 ISO Standard 13407 Human-Centred Design for Interactive Systems outlines UCD procedures and the importance of UCD methods that will be used in the methodology (ISO, 1999). Delikostidis, (2011) also identifies examples of different methods, which can be applied in UCD approaches. A list of the methods, which can be applied throughout all stages of the UCD is shown in Figure 22. The core of this research borrows from methods in produce design solutions and evaluate designs.

Analyse Requirements	Produce Design Solutions	Evaluate Designs
Survey / interview of existing users	Usability goal setting	Usability Inspections
User requirements interviews	Design guidelines and standards	Usability testing in the lab
User profiling		
Contextual Observations / interviews	Scenario-based design	Usability testing in the field
Diary keeping	Parallel design	Post-experience interviews
Task analysis	(paper- or working interface-) Prototyping	Heuristic evaluation
Competitive analysis	Card sorting	Focus groups
Card sorting	Focus groups	Satisfaction questionnaires
Personas	Individual interviews	Expert reviews
Scenarios of use	Surveys (online)	Surveys (online)
User / task models	Usability testing	Diagnostic evaluation
Interaction modelling		
Heuristic evaluation	Use cases	Performance testing
Usability testing	Style guide	Critical incidence technique
Evaluating existing system(s)	Wizard of Oz	Remote evaluation
Brainstorming	Heuristic evaluation	Logging
Affinity diagramming	Interface design patterns	
Requirements meeting	Rapid prototyping	

Figure 22: Methods of use and user research that can be used in UCD process by Delikostidis, (2011)

In summary, a UCD process, allows feedback of the user to be collected and incorporated from the start of the project. This can be matched against the project objectives to prioritize or modify them to have convergence with user-response and hence results in an application that is more relevant to the user with strategic and tactical objectives in mind. It has key benefits such as efficient time and cost management as the user's views are incorporated early on, enhancement of user-productivity, increased user satisfaction, and the achievement of the project objectives (Geoconnections, 2007). Several case studies underline how successfully implementing UCD can identify needs that have not been met (Delikostidis, 2011; Roth, 2013; Rühringer, 2018).

2.4.2. Use and User Requirements Analysis

As specified in the ISO 13407 standard (ISO, 1999), the user-centred design should begin with a thorough understanding of the needs and requirements of the users to know what they need and their current context of work. User requirement refers to those attributes that a product should have to perform from a users' perspective (Baxter et al., 2015). The importance of this process includes increased productivity, time efficiency, and enhancing the quality of work. Capturing these requirements has, in the past received little attention in the domain of cartography (Rühringer, 2018; van Elzakker & Wealands, 2007). It is however beneficial as the information is essential for a high-quality product. Delikostidis, (2011) and Roth et al., (2015) demonstrate the importance of involving the user in the development process to support building more usable interfaces.

In this research, the focus is not so much on conducting a user requirements analysis but on the outcomes of the previously conducted assessment. The data that will be used for this stage of the UCD process was the results of the analysis of Rühringer, (2018)'s work on Use and User Requirements of Ecosystem Service Maps. Rühringer, (2018)'s research conducted a user requirements analysis using methods such as interviews in determining the use and user requirements of ecosystem service maps. The user requirements in

Rühringer, (2018)'s research comprises the user and user profile, purpose of the map, the use context, and the business context of the map. The author conducts a study of ES maps at European, national and sub-national levels where she analyses requirements to gain insights on the perspectives if users as well as mapmakers of current ES maps as well as identify the usability issues that arise with these maps. Rühringer, (2018) detects some differences between the intended purpose of the map maker and the use purpose by the user and pointed out usability issues necessary for the user in decision-making.

2.4.3. Produce Design Solutions

Produce Design refers to the stage where the formal requirements derived from the user requirements are used in creating prototypes. At this stage using the information gathered in the user requirement analysis, activities may include user walkthroughs of prototypes, heuristics evaluations, and execution of user experience research activities (Baxter et al., 2015). Based on the findings and recommendations, these can range from a sketch of the rough concept to a complete design mock-up and prototype. Prototyping is a highly iterative process where visual mock-ups of the proposed functionality are implemented, initially probably as paper wireframes and eventually functioning prototypes (Geoconnections, 2007). In the mapping process, this is the stage of designing the map based on a set of cartographic guidelines as discussed in section 2.2.

Prototyping is the process of creating models to test designs/ concepts or ideas (Geoconnections, 2007). There are two types of prototypes; *low-fidelity prototypes* that are not working models, may or may not be static and are sometimes referred to as paper prototypes and *high-fidelity prototypes* which are generally more detailed and may allow user interaction such as on a browser (Geoconnections, 2007). Garrett, (2002) explains that the production of design solutions takes into account technical requirements such as device adaptability, accessibility or screen resolution, design requirements such as web site information architecture and screen topography, and navigational schema (Geoconnections, 2007). This stage involves the identification of map types and methods and incorporation of carto(graphic) design principles in designing the geo-visualization product.

The UCD approach has been used as an iterative process that allows for the most suitable product to be developed before it is released to the user (Lorena, 2019). Conducting an ongoing empirical evaluation throughout the design process is important to ensure and confirm that the usability and utility of the product are optimised in the final product. Iterative design and evaluation require the product to be continuously tested, validated, and refined to ensure a rigorous design process. Initial testing serves to provide feedback on utility and usability of the design before implementation or resource investments and later feedbacks serve to evaluate usability goals in more advanced design (van Elzakker & Wealands, 2007).

2.4.4. Usability

The third stage of the mapping process in UCD is the usability evaluation which should be integrated in the design solution process to create iterative evaluation and revision loops. There two types of evaluation: *Formative evaluation* which occurs throughout the design and development process to inform the project priorities and design decisions and *Summative evaluation* which occurs at the end of the process to evaluate the overall success of the interface (Tolochko, 2016). Initial iterations seek to retrieve rapid and early feedback on utility and usability before major commitments to design or resource investments, while later iterations focus on the evaluation of usability goals in more advanced stages. At all stages, it is necessary to obtain both qualitative and quantitative evaluation of data to inform the usability of design for modifications (Nielsen & Mack, 1994; van Elzakker & Wealands, 2007).

An early collection of the information of users is essential for establishing a goal style approach to designing a cartographic product. It ensures the design adequately supports the users as well as provides a foundation for achieving both utility and usability in the product (van Elzakker & Wealands, 2007). *Utility* refers to whether the system can perform functions required by the users to achieve their goals which may be readily accomplished by understanding what the users need to do and designing the product to address the goals (Nielsen, 1993; van Elzakker & Wealands, 2007). While *Usability* is defined by the International Standards Organization as the "extent to which a product can be used by specified users to achieve specified goals with *effectiveness* (accuracy and completeness), *efficiency* (minimal resource expenditure) and *satisfaction* (freedom from discomfort and positive attitude) in a specified context of use*,"* (van Elzakker & Wealands, 2007, p. 492) which is conceivably more difficult to achieve albeit providing major benefits. The ISO 9241-11 describes three key aspects of usability:

- **Effectiveness** as the accuracy and completeness with which specified users can achieve specified goals within an environment.
- **Efficiency** is the resources that are expended in relation to the accuracy and completeness of the goals achieved.
- **Satisfaction** as the comfort and acceptability of the system to its users and others affected by its use. (Bevan, Carter, Earthy, Geis, & Harker, 2016)

The new standards of ISO 9241-11 retain the previous concepts elaborated in 1988 that was focused on systems and service. It further extends this concept to include approaches to suitability and user experience e.g. including personal outcomes such as personal development and recognizing interrelated goals**,** *absence of negative consequences* – effectiveness has been associated with completing a task completely accurate, however, it is also important to consider potential negative consequence hence extending this definition to accuracy, completeness, and lack of negative consequences in achieving specific goals (Bevan et al., 2016). It also extends *satisfaction* to relate to aspects of cognitive, affective, and psychomotor response where it recognises the importance of user experiences such as positive attitudes and emotions resulting from the use of a product (Bevan et al., 2016).

Usability problems are design flaws that may be encountered by a user with a web map application and may be related to flexibility, efficiency, legibility, understandability, user control, feedback, visibility, ease of use, error prevention, consistency, accessibility, and standards (Nielsen, 1993; Tsou & Curran, 2008). Nielsen, (1993) lists five measures of usability adapted for usable interfaces where the first four focus on evaluating productivity and the latter on the user's engagement with the interface. They include:

1. Learnability meaning how quickly the user can understand the interface.
2. Efficiency refers to how quickly the user can interact with the interface once learning has occurred,
3. Memorability is a measure of how well users can return to the interface to pick up from before.
4. Error frequency and severity are how often, and fatal mistakes are in using the system.
5. Subjective satisfaction as to how much a user enjoys the interface (Nielsen, 1992, 1993; Roth et al., 2015).

Usability testing entails collecting data related to a set of usability parameters during observations of users' interaction with design, while usability inspection techniques are less formal for identifying issues involving inspection by evaluators such as designers, developers or users (Nielsen & Mack, 1994; van Elzakker & Wealands, 2007). Roth, Ross, & MacEachren, (2015) proposes a broad categorisation of the methods used in usability testing which include:

- Expert-based methods where feedback is given from consultants with training and experience in interface evaluation but with little or no prior knowledge of the interface that is to be evaluated.
- Theory-based methods that entail the developer to evaluate the interface themselves and to apply a rigorous evaluation using theoretical frameworks established and scientific research.
- User-based methods that solicit input and feedback from a representative set of target users who are essential to an effective UCD.

The user-based method can be costly in time, participant access and money hence Nielsen, (1993) recommends a small number of participants (3-5 target users) to be adequate for each evaluation (Nielsen, 1993; Roth et al., 2015). Various methods have been suggested under these categories such as guideline and Heuristic evaluation, scenario-based design, surveys, and interviews among others which may appear in two or more categories depending on the parameters.

3. METHODOLOGY

The purpose of this chapter is to describe the practical methods used in this thesis. The chapter outlines a description of the conceptual framework of the research (3.1), project plan (3.2), the chosen case study (3.3), and the methods for extracting user requirements, data acquisition and organisation, prototype design and implementation, and finally usability testing and adaptations. To achieve the expected outcomes, I adopt a User-centred Design (UCD) approach as explained by Van Elzakker & Wealands, (2007) and the mapping process adapted by (Tyner, 2010). As previously mentioned, the user requirements analysis is provided by (Rühringer, 2018)'s outcomes and emphasis of this research lies in the produce design solution and usability evaluation. This research focuses on developing a more generic reproducible application over a specific approach.

3.1. Conceptual Research Framework

This study focuses on two domain areas: marine ecosystem services and cartographic web mapping. Based on the research objectives this section further explains the fundamental concepts considered in adapting an interactive flow map for MES flows. The adapted framework is outlined in Figure 23. Mapping of ecosystems has been carried out by the use of several existing ES classifications which is adapted to suit the use case of this research (Burkhard & Maes, 2017). I use the IPBES classification system which can be tailored for the specific case study (Díaz et al., 2015) to understand indicators of marine fish flows; I also partly borrow from the cascade model by Haines-Young & Potschin, (2013) which denotes the relationship that goes from ecological structures and process to the well-being of people in the socio-ecological systems and the proposed integrated framework on ES supply chain by (Daw et al., 2016; Drakou et al., 2018) which focuses on the supply and benefit value chain to explain the case of marine flows. The data is based on MES flows from the Marine Ecosystem, biological processes and functions are responsible for the services produced. Overlapping with this is the social-ecological systems where we have three key components: ES supply, demand, and flows. The supply is mobilized by the flows and the flows are triggered by the demand. The spatial locations (represented as $S_{1\ldots,n}$) denoted for each of the components can be the same or different locations across the globe. The movement of these flows are then designed and mapped in the interactive web map system. Within the cartographic web mapping domain concepts of design, implementation and users involved are considered. Components that are referred to in the design space entail use case scenarios and user requirements which are derived from end-user requirement analysis. Others include (carto-)graphic design principles, taxonomies of information visualization, principles of designing OD flow maps, and graph drawing principles that are used within the design space. In the implementation of the interactive web map prototype components used are the data store technologies, methods of data distribution, and implementation of the web client application through front-end technologies.

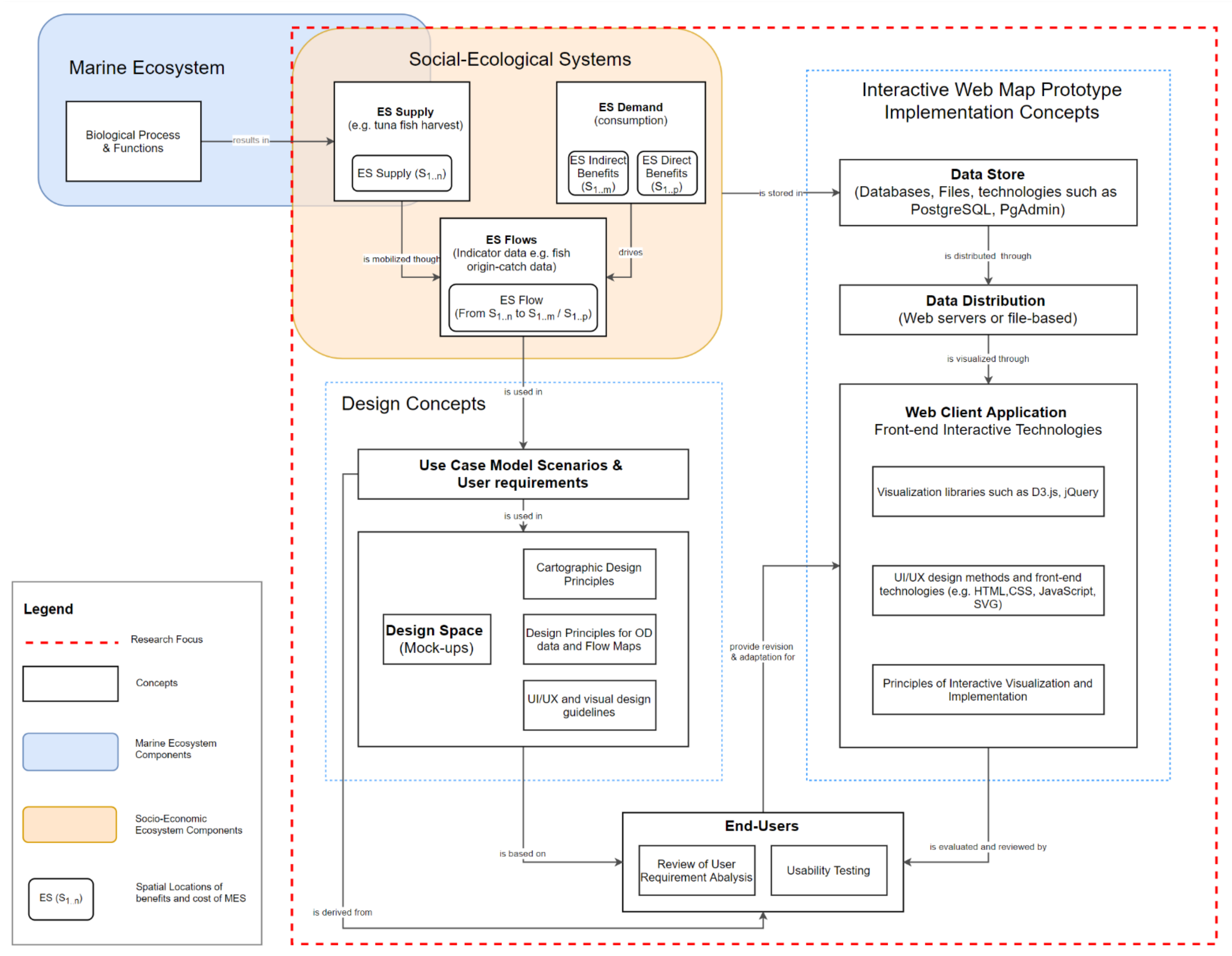


Figure 23: Conceptual Framework of interactive mapping of ecosystem flow benefits modified and adapted from ((Drakou et al., 2018)) framework and (Haines-Young & Potschin, 2013)cascade framework on ecosystem service assessment

3.2. Project Plan

This section provides an overview of how the project shall be carried including introducing the practical implementation steps and the research framework adopted. A User-centred Design (UCD) approach is considered for the design and implementation of the prototype with the goal of soliciting feedback from users during the design and implementation stage and to test the usability of the final prototype. I focus on the first 5 stages of Robinson et al., (2005)'s UCD process in the methodology: Work domain analysis, here referring to the needs assessment or requirement analysis, conceptual development which describes the formalization of requirements and guidelines for the application in designing the web map, prototyping which is part of an iterative process of creating the web map prototype with the proposed functionality and the usability testing assessment to receive feedback on prototype from users and finally the implementation stage incorporating changes from previous evaluations.

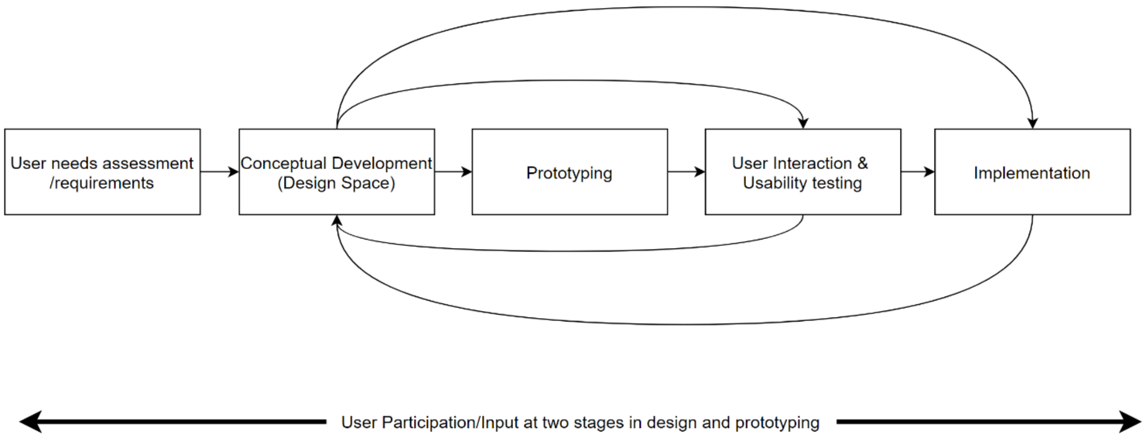


Figure 24: The flowchart stages as an adaptation of UCD process discussed by (Tolochko, 2016) and (Robinson et al., 2005) which draws from cartographic applications of user-centred design primarily from (Haklay & Tobón, 2003) and (Slocum, Cliburn, Feddema, & Miller, 2003)

The UCD approach is a highly iterative design process and suggests that the target group should be involved in multiple stages, informing the implementation through iterative evaluation indicated in Figure 24 (Tolochko, 2016). Ideally, the user should participate at several stages of the design process from the beginning, however, to limit the scope of this research, a user needs assessment that was already carried out by Rühringer, (2018), shall be reviewed to determine the use case model and the application requirements. The end-user shall therefore mainly be involved in at least two iterations for usability testing of the application designs which will be adapted to the final prototype and a second interview testing with a project expert to give general feedback on the final prototype.

3.2.1. Overview of the Research Framework/ Methodology

The research methodology based on the prototypical framework is further elaborated in Figure 25. I start with a thorough literature review of MES, the case study, and the user requirement analysis. Then carry out data acquisition and organize and restructure the information. From here I outline the use and user requirements derived from literature and use this together with the acquired data to come up with user profile and use case model, which then informs the formal tasks and functionalities of the application. In the next step, the functionalities are used in the designing of the web map navigational layout and (carto-)graphic visualizations centred on literature review of design principles. The resulting outcomes are visual design mock-ups or concepts which are then employed in determining the implementation technologies and steps. I first store the data in a database, then reading from this database, I restructure the data into the correct final format for the next step which is the front-end visualization. After creating the initial prototype, I carry out a two-step iterative usability testing to adapt this prototype to meet the user needs and address the issues that exist. I then adapt the prototype for the final implementation and deployment.

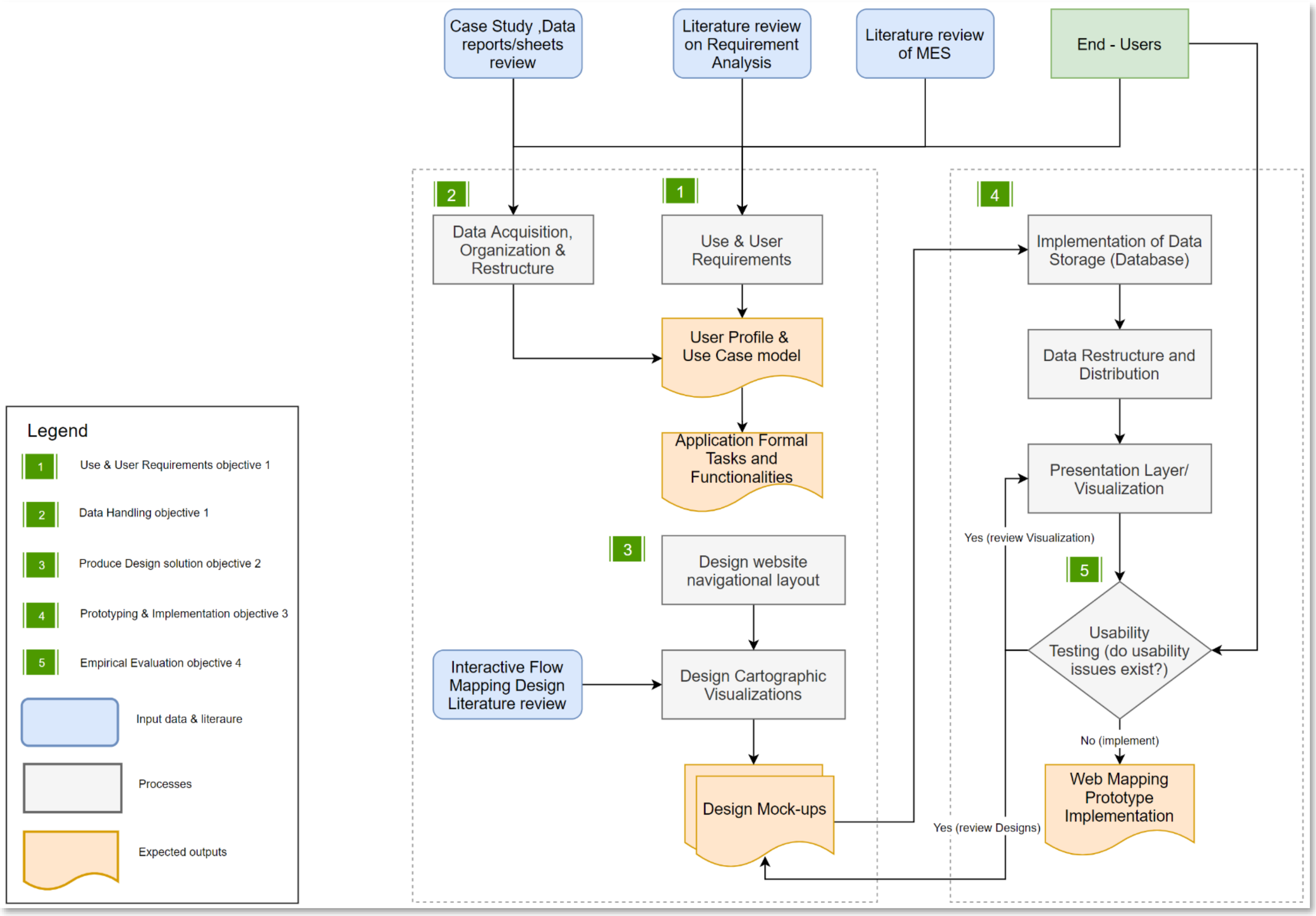


Figure 25: Workflow of research design and methods

3.3. Case Study

One of the main recommendations of Rühringer, (2018)'s work is that the map creation should be created with a specific user in mind. In this case, I focus the demonstration of the interactive web map on the Pacific Possible project on Tuna fisheries for the Western and Central Pacific Ocean (WCPO) region (World Bank and Nicholas Institute, 2016). The aim is to create an interactive web map as a better communication tool and test this with the case of WCPO, an area whose benefits from seafood are realized across the globe. As previously mentioned, the information from reports fail to show a holistic picture due to the way they are presented as charts, lists and numbers. Hence the contributions to global well-being of a local fishery in Pacific Island countries is hardly considered in the fisheries management or in the decision-making at a trans-national to the local level (Hamilton et al., 2011). Improving the way, we map this data is the first step towards more efficiently communicating this information. An interactive web mapping application for querying and visualizing marine flow benefits will have a significant impact on decision-support systems and communication.

The WCPO region includes the Pacific Island countries (PICs) and extends south below New Zealand to the Bering Sea in the North (Figure 26). This region collectively forms the basis of the world's most valuable and largest fisheries, such as tuna. The region is home to four species of valuable tuna resource, the fisheries supply 60% of the world's tuna. The benefits have thus been highly significant for some PICs despite not being evenly distributed e.g. 36% of Gross Domestic Product (GDP) in Tuvalu or 10% in The Federated States of Micronesia (FSM) (World Bank and Nicholas Institute, 2016).

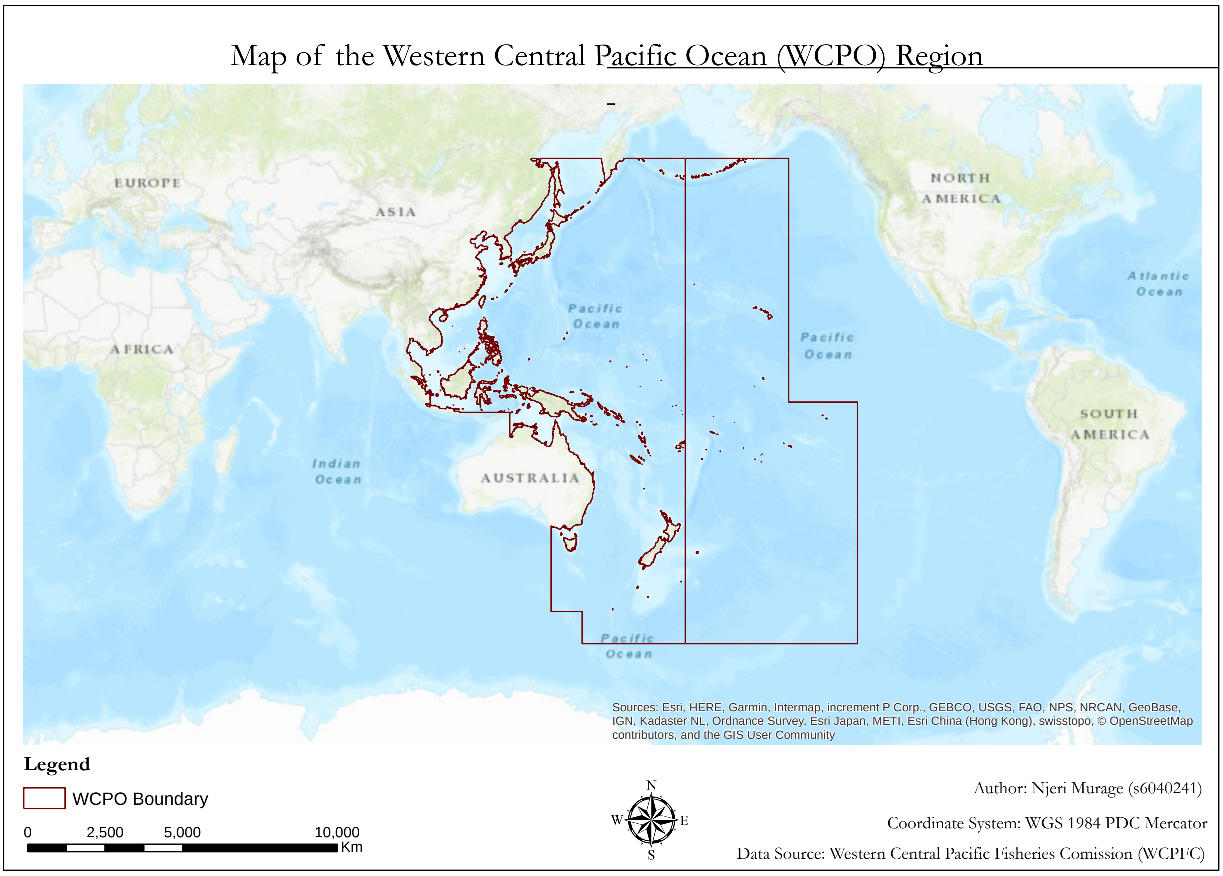


Figure 26: Western Central Pacific Ocean Study Area

3.3.1. Purpose of the Pacific Possible Project

The overall purpose of this project would be for policy development and support and managerial decision making. The objectives of the Pacific possible report entailed defining the key drivers of performance for the resource, then describing the current economic contributions from the resource and past trends as the baseline, describing the expected changes in the direction of the indicators of external drivers and finally providing a plausible best-case scenario in 2040 based on policy strategies and expected changes in key drivers (World Bank and Nicholas Institute, 2016). The Pacific Possible project describes a scenario on how much more WCPO's tuna resources would sustainably contribute to economies of PICs for the year 2040 in a plausible best-case scenario by 2040. The approach taken includes observing recent trends in fisheries that have been summarized in the region, analysing the number of key external forces expected to drive performance of WCPO tuna fisheries over next 25 years, and using this information to describe a potential scenario for the region dependent upon the implementation of the decision policies outlined in the Regional Roadmap for Sustainable Pacific Fisheries (World Bank and Nicholas Institute, 2016).

The WCPO region covers 8% of the global ocean with the national waters of several countries as well as areas beyond national jurisdiction covered under the Convention on Conservation and Management of High Migratory Fish Stocks in the WCPO (World Bank and Nicholas Institute, 2016). Movement of tuna occurs in parts within waters under the jurisdiction of the Pacific Island countries and in particular the 11 members of the World Bank which control over 55% of the WCPO area and approximately 5% of the global oceans (World Bank and Nicholas Institute, 2016).

WCPO region contains stocks of four tuna species that are commercially harvested: Albacore, Bigeye, Skipjack, and Yellowfin. These four stocks of tuna move widely through the WCPO region and are harvested by industrial fishing vessels with modern technology. The diverse range of fisheries is defined by the methods of fishing used which include small-scale artisanal operations, industrial purse-seine operations. (capturing largely skipjack and yellowfin), industrial longline operations, and industrial pole-and-line operations. The two largest of the fisheries are the purse seine fishery and the longline fishery both in volume and value (Williams & Terawasi, 2015; World Bank and Nicholas Institute, 2016). Therefore, the pacific possible report focuses on these two methods.

WCPO purse seine and tropical longline tuna fish often originate in Pacific Island waters and end with consumers in Europe, Japan, or North America (World Bank and Nicholas Institute, 2016). Therefore, in analysing the economic benefits World Bank and Nicholas Institute, (2016) consider these fisheries as dynamic systems that include all components of a supply chain. From the natural resource stock which then produces a flow of benefits to users along the chain. This is shown in the form of a generic simple value chain (World Bank and Nicholas Institute, 2016). In this research, therefore, the main objective is to translate the visualization of these flows of benefits from simple global supply value chain pie charts as seen in Figure 27 to an interactive map in which users can deduce further details. The units of analysis that are considered for demonstration in this research are decided based on criteria described in section 3.5.3.

3.3.2. Units of Analysis for WCPO Case Study

Economic contributions and weight in tons are measured at each component of the value chain. They are often measured by their annual contributions to a country or group of countries. While these fisheries form complex, global value chains, the best available information for each is summarized along with the three general segments of the chain: *resource owners, harvesting units, processing segment* (canning and loining; including distribution), and *retailing segment*. *Resource* owner here refers to those countries that have jurisdiction over tuna harvest within the waters. These can be countries within the WCPO region such as the Pacific Island Countries (PICs) or countries that pay for rent access to the fish stock where the theory of land rents to accessing fishing grounds under the nation's control applies (World Bank and Nicholas Institute, 2016). The Parties to the Nauru Agreement (PNA) member countries and Tokelau introduced the vessel day scheme (VDS) where foreign countries pay for access to the resource. *Harvesting* units are the fleet vessel owners that harvest within the WCPO waters including tuna trading companies working with harvesters where mobile fleets follow tuna stock as they move across national boundaries. In the *processing segment*, the catch is mainly canned and exported to several markets for consumption such as European and North American markets as a result of an increasingly globalized supply chain (Hamilton et al., 2011). In 2010 the major tuna canner was Thailand with main canning taking place in Bangkok and this is followed by Japan, Ecuador, and the Philippines. The retailing segment is not considered in this research as the data provided is not specific to the WCPO region but the entire globe.

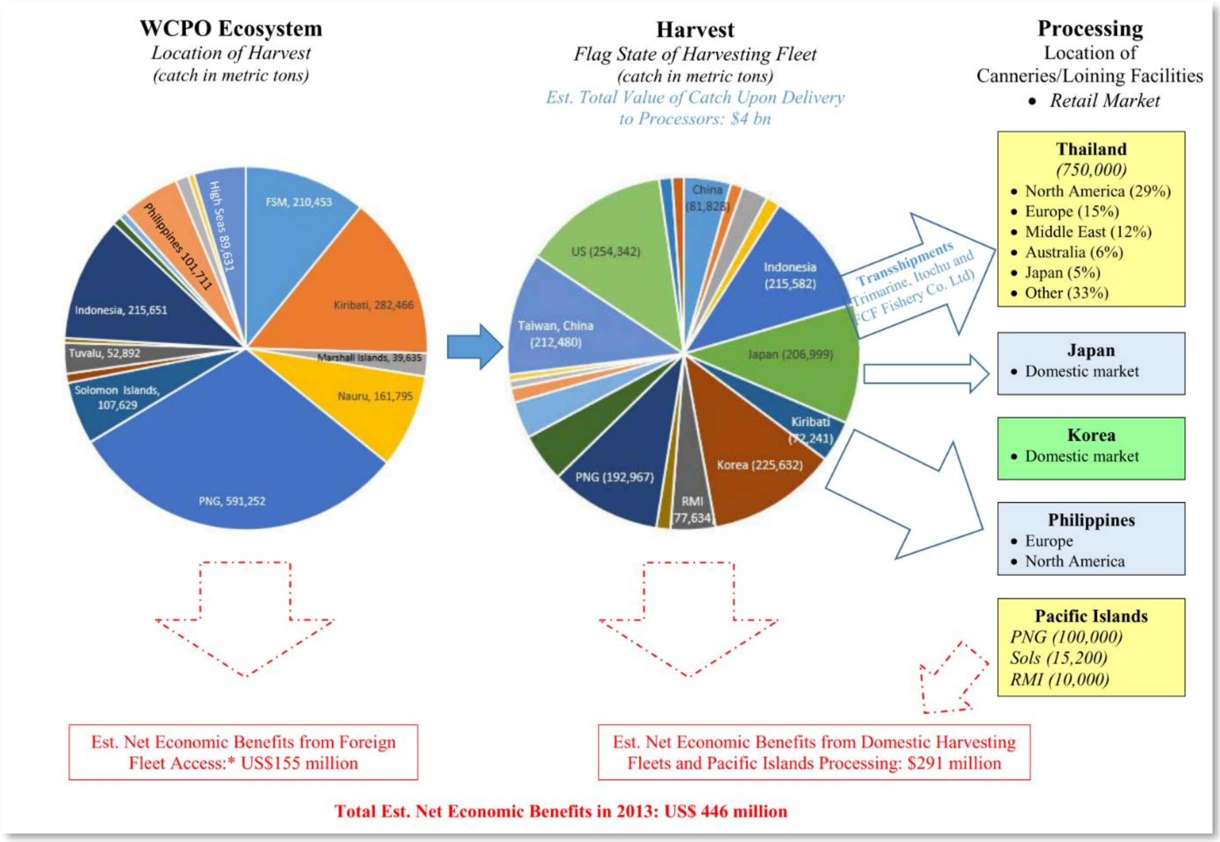


Figure 27: An illustration of data representation of WCPO Purse Seine Tuna Fishery Value Chain in 2013 with Net Economic benefit as depicted in World Bank & Nicholas Institute (2016)

As mentioned in the introduction this global supply chain provides unique characteristics such as the location of fish demand that may be the same or different from the supply. Drakou et al., (2018) defined these characteristic flows in the WCPO region in 3 states:

- One-to-one flows where the cost and benefits trade-off is observed in the same location of ES supply and demand. There is no intermediary beneficiary in this flow an example of such a case is Japan which has registered vessels fishing in the region, then processing is done domestically and 95% of the products are distributed and consumed in the Japanese market.
- Closed-loop flows which refer to where the ES demand in a location triggers flow to different locations which are intermediary beneficiaries as the agents bear the cost and benefit and the final benefit is then received in initial location of demand e.g. countries like the US send large fleets to harvest in WCPO, most of which is processed in Thailand and exported back to the US for consumption.
- Open-loop flows refer to a fragmented flow with several points of supply and demand generating multiple flows from different locations. The different parts of the global supply chain here spatially differ e.g. Spanish fleet buys access to fish which is then processed by Thailand and transhipped to other parts of Europe. (Drakou et al., 2018).

This case study as with other similar cases in economic trade and global supply chain differs from the traditional examples explained in Origin Destination maps such as flight information or migration. This is because the mentioned OD datasets have a clear start to end path without the intricacies of the explained flow loops where a location can play several roles (origin or destination), or differing scales(Jenny et al., 2017). These types of flows including the mix of resolutions in data reporting in a global supply chain increase the complexities of the cases beyond the ordinary origin-destination data. Hence the need to adopt branching flow mapping techniques in an interactive web map with information that can be interactively changed to accommodate this. In the case of WCPO, better communicating the baseline data is important in analysing and understanding the current situation and its drivers of change for decision making and scenario analysis and it also enables information that was previously not considered in fisheries management to be considered. I, therefore, focus on the visualization of the baseline data through an interactive flow map application.

3.4. Use and User Requirements

This section describes the methods used to derive the use and users' requirements from a general perspective and consequently from a use-case based scenario. This is the initial source of information to achieve the first objective *"To analyse formerly defined user requirements and delineate as well as systematically organize the set of suitable indicator data for mapping of MES flows in the WCPO region."* and here I seek to answer the first research question:

i. What are the requirements by the end-user for the system based on analysis of user research to communicate marine fish flows for the WCPO region?

I look at understanding the various ecosystem service users, the users of the pacific possible project, the data available, the purpose of the pacific possible project, and formulate a clear structure around it thereby tackling the main objective through the first specific objective. The methodology applied here is *information gathering* and it involved in-depth research and literature review to examine the necessary information from publications, reports, datasheets, and previous research is done. Maguire & Bevan, (2002) propose various methods suitable for information gathering when carrying out a user requirements analysis such as secondary market research, the context of use analysis, task analysis, among others. Since previous research has already been carried out for this stage, I mainly use secondary market research and the context of use analysis to have a conclusive outcome.

Secondary research mainly involves researching published sources which may include data reports, research reports, demographic information among others that give insight on the range of possible users and user market (Maguire & Bevan, 2002). The main source of data for this method is provided by Rühringer (2018)'s work on User Requirements of Ecosystem Service Maps Analysing Decision Makers within the Use and User requirements of Ecosystem Service Maps. This method is considered suitable for this research as there is sufficient information source and it saves on the cost of time and resources for work already carried out. While the context of use analysis here mainly involves the quality of the product being dependant on a good understanding of the context of its use. Capturing contextual information is important in helping to specify user requirements for a specific study (Maguire & Bevan, 2002). To gather contextual information I carried out a review on data and information reports on the Pacific Possible project by World Bank and Nicholas Institute, (2016), datasheets provided by Fisheries Forum Agency (FFA, 2016) as well as information availed by the report by Hamilton et al., (2011). Guiding questions, I considered in gathering information here include:

- Who are the users of ES maps and what are their requirements?
- Who are the users of the Pacific Possible project and requirements?
- What are the main purpose for the various users and use context?
- What are their goals, sub-goals, and tasks?

3.4.1. General Criteria for identifying and selecting users

The research focuses on developing a more generic reproducible application where I outline the user at general levels of decision-making functions such as the global, national, and sub-national levels in information gathering. I then draw specific users from the case study of the WCPO region for purposes of usability testing in analysing the context of use. The outcomes of Rühringer, (2018)'s work included user-profiles, use case scenarios, and recommendations for the design of ES maps. User profiles and use cases are methods that support the development of the map product (Baxter et al., 2015). A user profile has a detailed description of attributes of prospective users, their user types and attributes such as education, knowledge of the user, etc.(Baxter et al., 2015; Nielsen & Mack, 1994). This method helps to understand who the product is for. Rühringer, (2018) also provides a complementary use case for each user profile describing a sample case of an ecosystem service map. The use case scenario has the value of a further understanding of the potential user. Further, to this, I chose a minimum selection criterion to justify the type of user profile to be used in the study. This allows us to now merge the outcomes of Rühringer, (2018)'s work to the chosen use case study. The criterion in Table 6 below is informed by the literature review on the essential needs and use of an Ecosystem Service map.

Table 6: User selection Pre-requisite

User Profile Criteria of Inclusion	
Age	Any
Highest education	Should have at least a bachelor's degree to understand the multi-disciplinary context of the use
Educational background	Any (Multi-disciplinary scope from marine science, fisheries, policy, and management.)
Gender	Any
Profession	May include a range of professions from scientists, policymakers, fisheries managers, fishermen, etc. (it is meant to serve a wide range of users from regional to community level)
Map use experience	Any (Include both experts and non-experts to see the different understanding and interactions.)
Ecosystem service maps knowledge	Any (Should serve both those who are familiar and not familiar with ecosystem service concepts.)
Basic digital computer skills	Able to (learn/understand how to) use a browser and digital map interactivity use such as clicking, zooming, browsing, and typing to search.
Roles	Different levels of users: - Decision-makers at the regional level - Decision maker at national level - Scientists (marine/ecosystem/GIS) - Local experts (e.g. related to fisheries or economics)
Use Case Relevance	Based on the project the users should have a role to play in the purpose of the project as what is claimed to be the end-users e.g. decision-maker at the regional level, managers in a fisheries commission, etc..

3.5. Data Acquisition and Pre-processing

An understanding of the data and user requirements will allow us to conceptualize the functional and non-functional requirements of the system. I start by explaining the methods to answer the second research question for the first objective *"To analyse formerly defined user requirements and delineate as well as systematically organize the set of suitable indicator data for mapping of MES flows in the WCPO region."*

ii. What are the chosen indicator data and in what way shall this be organised based on user requirements in preparation for data storage and distribution?

This section looks at the available data, the general features and attributes of the data, the data specificities, and general criteria for selection of dataset and finally the acquired and restructured datasets. I outline the data acquisition, exploration, and pre-processing. Data storage and data management are explained further in 3.7 on implementation.

3.5.1. Data Acquisition

The data used for demonstration of an interactive web map of flows of benefits was extracted manually through reading reports, publications and datasheets mainly by World Bank and Nicholas Institute, (2016), the Hamilton et al., (2011) report, FFA, (2016) and Williams & Terawasi, (2015) report. The data used is for the case of the World Bank's Pacific Possible Project and is described in Table 7.

Table 7: Available Data sets and their data sources

Dataset	Description	Status	Year	Extent
WCPO boundaries	ESRI shapefiles	Publicly available	Current	WCPO region
FFA Catch and Catch Values (in metric Tons).	Information published by the Pacific Islands Forum Fisheries Agency (FFA, 2016)	Available	1997 - 2015	Global
Tuna volumes in processing and final market locations	.xlsx file of Aggregated Catch data (Fleet Origin, Processing, and Final Market). Published market studies (Hamilton et al., 2011; World Bank, 2016).	Available	1997 - 2015	Global
Country and Continental Boundaries	ArcGIS Hub	Available for download	current	Global

3.5.2. General Features of Data

The data mainly considered source from the FFA datasheet (available through personal contacts) and the World Bank and Nicholas Institue report as they were the most complete and available (FFA, 2016; World Bank and Nicholas Institute, 2016). It involved shifting information manually and storing in excel sheets for comparison of both the sources. I created a spreadsheet of resources and data available indicators, attributes, and features. The chosen dataset for the specific web map application should be closer to the characteristics of Origin-Destination data. As mentioned OD mapping is a way of representing spatial interactions such as the flows of data between pairs of spatial locations which can either be branching or non-branching (Boyandin, 2013). Marine ES flows are characteristic of branching OD data. Such spatial interactions require the data to have relationships and to be linked. The general features for visualizing a complex network of flows should include:

- Area nodes referred to as origin (start node) and destination (end node) or intermediary destinations for the case of branching origin flow maps.
- The data should have relationships i.e. it should be indicative that information flows from one segment to another.
- The data should finally have consistent spatial and temporal scales for ease of mapping flows.
- The data should have a consistent unit of value across the different segments (nodes).

Data Attributes and Units

The aim here is to visualize the baseline or current contributions and trends based on data mainly from the World Bank and Nicholas Institute, (2016). The economic contributions made in WCPO are observed at 4 different segments and the available data provided in the global supply chain contains the following attributes and units (Table 8).

Table 8: Data Measurement and Attribute

Dataset	Observed Indicators	Unit of Measurement (Attributes)
Resource Owner	The fish-origin catch (weight and value)	Metric Tons $USD value %
Fleet Owner	The catch by national fleet (weight and value)	Metric Tons $USD value %
Processing Region	Fish Processing and export biomass	Metric Tons %
Market	Fish Processing and export biomass	%

Resource (origin of harvest): Refers to the countries that have ownership of the resource or where fish is caught. The data is provided is in metric tons and US dollar value. The data presented in FFA differs by a margin of 2% to that provided by the WCPFC and figures shown in the World Bank and Nicholas Institute, (2016) report, however, we mainly use that from World Bank and Nicholas Institute, (2016). The spatial resolution of this data is at the country level. Data is available from 1997 to 2015.

Harvest (fleet owner): The countries that send fleets to fish within the waters of the WCPO region. Data is provided by the FFA report in metric tons as well as in US dollar value. This is also available for the period between 1997 to 2015, however, the World Bank and Nicholas Institue report gives more in-depth information such as destination for processing, number of vessels among other details for the year 2013. The spatial resolution of this data is at the country level.

Processing: The locations or countries that carry out the processing of the tuna fish through canning and loining. Data is only available from World Bank and Nicholas Institue report and Hamilton et. Al (2011) report. This is in as metric tons and percentage of processing. The final markets as to where the tuna is exported are also provided for some of the countries and are mainly in %. The spatial resolution of these datasets varies between country-level and trans-national or continental levels.

3.5.3. General criteria on Deciding what data to Consider

Choosing a criterion on what data to focus on for prototyping allows us to access the data and determine if it serves the needs required. To understand the data I explored the information extracted in Excel sheets and GIS software. van Oort, (2006) outlines three steps to be addressed in assessing if a dataset is fit for use. They include searching for spatial datasets that contains information for the intended application, exploring the legal and financial constraints, and finding out if the spatial data quality is sufficient for the application. The first two steps were already met as the data was readily provided for the specific use case of WCPO without legal or financial constraints. International Organization for Standardization (ISO) defines the quality of data as the "totality of characteristics of a product that bear on its ability to satisfy the stated and implied needs" in other terms fitness for use (ISO, 1986). Based on the factors to consider in spatial data quality and the literature review of the case study, I propose that the data used should meet a minimum criterion as shown in Table 9 below to make it fit for use in mapping flows of benefits of marine tuna fish across the globe. The attribute factors chosen are based on derived meanings from van Oort, (2006) on assessing the quality.

Table 9: Data Selection Criteria

Attribute	Description	Criteria
Logical Consistency/ Homogeneity	Are the observations derived logical? - Locational consistency (spatial) - Temporal consistency (time collected) - Domain consistency (attribute) - Topological consistency (relationships)	- Data should have no negative values for all attributes. - Data should have the same spatial scales in one segment(beneficiary type) but not necessarily at different segments. - Data should generally be provided for almost the same time period. - The value of measure should be consistent among all segments e.g. metric tons, %. - Data relationships should show at least one or more linkages from catch to harvest to processing and export.
Spatial and Temporal Completeness	Is the dataset complete? Both spatially and temporal?	- Data should at least be available for 50% of the listed participating areas (countries or regions) per segment. - Total values should also be available for the entire chosen year (s)
Attribute Accuracy	Refers to what has been measured and how is the measurement reported? e.g. based on measurements of scale include nominal, ordinal, interval, and ratio scales	The measurements taken should be of the same accuracy and precision based on the report on how the data was collected.
Resolution and Accuracy	At what level of resolution is the data available? - Spatial resolution - Temporal resolution	- Data can be at national/country or trans-national/regional levels.

		- Data can be available for a one year time period or aggregated to at least 5 year period that is indicative of other years.
Usage and Purpose	What is the purpose of use?	- Data should be suitable for answering the goals and tasks of the user.

Specific Criteria for the selected case study

Based on the description of the available data, and the criterion above, I chose datasets specific to the WCPO use case by answering the formulated questions:

1. Is data available for resource, harvest, and processing?
2. Is data available and complete for most recent years against other segments?
3. Which type of fishing gear data is the most complete?
4. Are the datasets available for specific species or is it aggregated for all species?
5. Out of the above checks for how many countries are datasets available for the various stages of flow (i.e. Is data linked from catch to harvest to processing and final markets?)
6. Can the data be attributed to a spatial location or area(node)?

Uniqueness/ Specificities of Data

In the Case Study chosen I aim to map a complex network of relationships of branching flow map data. This data is unique and may bring challenges in several different ways as described in the background information. Some of these unique attributes are:

- The data is available for the specified years for the resource and harvest segment. However, for process and market, the data is aggregated or provided as an indicative measure derived from a specific year.
- The data at some segments have similar spatial resolution at the country level and other segments have mixed resolutions e.g. the market information is at both the national and regional levels.
- Some measurement values are available in certain regions and missing in others or available for certain years may be missing for different years e.g. the actual value measurements for the process to market information are missing for some of the countries listed as processing.
- The relationships in the data are described in 3 ways; one-too-one loop where resource/harvest, process, and the market may be the same location, closed-loop where resource/harvest and market are the same location but processed in a different location or open-loop where all three segments differ. Hence introducing challenges in the code design of flow mapping.
- Some relationships of the data are not linked e.g. from catch to processing.

The approach to solving some of these issues includes either leaving out much of the data based on set criteria or adopting some specific design guidelines for visualizing the data as explained in chapter 4.

3.6. Conceptual Design (Wireframing)

To create a usable web mapping application, it is important to design it based on general conventions and guidelines to ensure it meets the needs of an end-user. In this section, we discuss the methods and tools used in the conceptual design of the prototype. The expected outputs are low fidelity prototypes or mock-up from design rules and guidelines explained in the literature review. This section, therefore, addresses the second research objective; *"To design an interactive web mapping application for the visualization of marine ES flows"*. The research questions include:

i. What technologies are needed to design an interactive web mapping application for marine fish trade flows?
ii. What are the steps required in designing of the application?
iii. Which scientific methods will be used in determining suitable geo-visualization approaches and cartographic designs based on the chosen set of indicator data for the end-user requirements?

This is the first stage of the produce design solution in the UCD process as explained in the literature review (section 2.4.3). Baxter et al., (2015) refers to this stage as the activities that pertain to the derivation of the formal requirements from the user requirement and producing low fidelity or high-fidelity prototyping based on heuristics and principles. To achieve this, I look at the available data and formal requirements derived in phase one and use this to choose specific design outputs for the product. The user requirement from Rühringer, (2018)'s research identified users, purpose, and general needs for the user. This shall then be used to create use case scenarios that can be used in identifying the functional needs for the application. Scenario-based design is used to capture the needs and actions or tasks of the user. The functional needs are then used in creation of both low-fidelity and high-fidelity prototypes to represent both user interface and the interactions in the application. The approach to the design entails understanding the data and the user i.e. **data design**, the methods employed for visualization or **representation design** and strategy employed for interaction of the application as **interaction design**.

3.6.1. Data Design and Functional Requirements

A scenario-based design refers to a collection of techniques in which the future use or intended use tasks of a product is well described at an early point in the development process (Rosson, Carroll, Tech, & Va, 2002). Like the general UCD approach, it shifts focus from pure functioning specification to describing the user and how the user will accomplish work tasks and activities for an intended goal. Case scenarios consist of a setting, situation, and user with motivation, knowledge, and certain capabilities. It describes actions the user intends to perform. The scenario-based method has gained popularity in interactive system design because it enables rapid communication on the possible usage and concerns among many different stakeholders. Scenarios can be simple or detailed depending on the system and it allows designers to quickly give ideas and get feedback to refine their ideas before sketching or prototyping (Rosson et al., 2002).

Often developers or designers tend to generate solutions quickly before properly analysing the possible moves and problems. The result is that the design may be too far gone to abandon the idea even when the solution is not appropriate. They may also not analyse a problem and their own solutions very well and may consider too few alternatives when exploring the problem space. Scenario-based design helps minimize these shortcomings in three ways (Rosson et al., 2002):

Scenario-based design is concrete but rough. Design analysis is usually indeterminate, due to the act of design changes. Requirements will often change and when designs incorporate rapidly evolving technology, the change is even more rapid. In most cases, refinement of software technology and new opportunities propel a new generation of designs. Design representations that are concrete but flexible help manage ambiguous dynamic situations. Initial scenarios are often rough to provide quick feedback and allow for change(Rosson et al., 2002).

Scenarios maintain an orientation to people's needs. Due to too many possible solutions, designers need constraints especially with the current state of technology which makes some solutions impossible and other irresistible. They are caught up in the latest technologies and gizmos and may be biased towards familiar technology hence constraints based on what the user needs and actions required are vital to enable narrowing down to the right choice of technology and solution offered. Scenarios are work-oriented objects that describe the terms of work that users would like to achieve and hence address "representational bias" in human cognition (Kahneman & Tversky, 1972; Rosson et al., 2002). Reuse of familiar ideas is one constraint that may apply in solution-first problem-solving.

Scenarios are evocative and lead to many questions being raised. A balancing act is required between thinking and doing where one may impede progress in the other. Reflection of your work is not always comfortable, however, creating opportunities for reflection and questioning promotes the integration of different perspectives and raises issues that designers may have not been aware of. Case scenarios allow one to reflect on the ideas in the context of the user and design solution provided (Rosson et al., 2002).

In this research, I will create two sample case scenarios based on the outcomes of the user requirement analysis. The case scenario shall include profile information of the user e.g. the demography, education level, domain expertise as presented in Table 6 (section 3.4.1) on use case profile pre-requisite. It will also include the chosen use case scenario based on derived goals and purposes from the user requirement and the case study. Finally, a set of tasks to be achieved will be included to determine what actions are required to achieve these. These can then inform the functional requirement for the website. The functional requirement is a summary of all functions, components, and tasks identified from the use case scenarios.

Task Identification

To determine the tasks used in understanding the formal requirements and for creating usability questions as well I employ Shneiderman's Visual Information-seeking Mantra and the type by task taxonomy (TTT) proposed as well as Bertin, (1983) reading levels (Maleki, 2016; Shneiderman, 1996). I take a similar approach to that by Maleki, (2016) who related Bertin, (1983)'s reading levels to Shneiderman's visual information seeking mantra. In this, I also include a related task as an intermediate level to capture tasks showing relationships. These tasks are later translated based on geographic difficulty levels for the formulation of questions in usability testing (section 3.8). These tasks determined the functional requirements for use in creating visual mock-ups in Table 10.

Table 10: Bertin's reading levels related to Shneiderman's Information Seeking mantra and TTT

Bertin's reading levels	Shneiderman's Visual Information-seeking Mantra	Tasks examples
Elementary	Details on Demand	How many metric tons does country X catch as a resource owner? What is the dollar value for country Y's resource?
Intermediate	Zoom and Filter, Relate (capture relationships)	Which country has the highest number of fleets? Which is the largest processing country? Country X exports tuna fish to which countries?
Overall	Overview	Which regions have participated mainly as consumers?

3.6.2. Representation Design

The method employed in the creation of visual mock-ups is prototyping as described in the literature review. Geoconnections, (2007) refer to prototyping as the process of creating models to test the concepts, ideas, or designs. Prototypes can be low fidelity which refers to static models or not working e.g. paper prototypes/hand-drawn sketches. This is a rough conceptualization of translating the functional requirements into actual visual ideas. It entails using principles of data visualization and web mapping techniques (section 2.2). The design pertains to both the application layout and the visualization graphics or composition.

Technologies that were used in this stage are paper sketching, MockFlow for basic wireframe layout, and AdobeXD for a high-fidelity prototype of the User interface and User experience. As mentioned, prototyping is an iterative process and during the design process feedback and reviews were provided by the visualization supervisor. AdobeXD was chosen as the software to carry out prototype designs for several reasons. It easily allows for reviewers to provide feedback on each part of the design such as different pages including giving specific details to specific components within the design. Compared to other wireframing software's AdobeXD is great as it allows for a basic implementation of user experience where one can create an almost real-like feel of the website with functioning clicks and changes being seen hence it enables quick capturing of the near-real application. The other reasons include that most of its important features are freely accessible to use and that it supports a plethora of user design kits from the community which allows quick implementation of realistic mock-ups (https://www.adobe.com/products/xd.html).

Web Map Layout

Map layout refers to the placement of map elements or non-map elements in the application (Muehlenhaus 2013). The layout of the interactive web application is based on the proposed design guidelines mentioned in the literature review (section 2.2.3). A thorough review was carried out to understand what the most appropriate design principles and conventions are. To create the layout the following rules and guidelines already presented are used:

- The overarching visual design principles(Lovett, 1999; Usability.gov, n.d.)
- Norman, (1988)'s 7 fundamental design rules.
- Shneiderman's eight golden rules are also considered and discussed in the results of the final mock-ups with a focus only 6 out the 8 which include: striving for consistency, cater for universal usability, offer informative feedback, design dialogs to yield closure, prevent errors and reduce short-term memory load by Shneiderman and Plaisant (2010) and the visual information seeking mantra (Shneiderman, 1996).

The initial wireframing of the layout is created by hand-drawn sketches and translated using the MockFlow app (https://mockflow.com/). MockFlow is used to create the overall layout of each component of the website before proceeding to include the elements of the graphical visualization. MockFlow, despite having minimal features, is chosen for the basic initial concepts because it is easy to use or geared toward beginners and can allow one to create initial simple layouts due to available integrated UI kits and intuitive user interface. The layout for the application is based on the graphics chosen and shall be presented in the results.

Web Map Composition

As discussed in the literature review, the choice of map type and elements is dependent on the data. Due to the unique type of the data and its characteristic nature to resemble OD data I focus on the use of flow maps for visualization. However, other supplementary maps and graphs will be included to support a holistic understanding of the case being mapped. The flows of benefits of MES are captured based on indicators including weight in metric tons, dollar value, and %share, these are quantitative data. Map type choices, symbolization, and supplementary graphics are based on the measurement scale of this data and the following cartographic and visualization design principles discussed in the literature:

- Cartographic principle and proposed techniques (Turchenko, 2018).
- OD and Flow mapping principles and representation techniques(Boyandin, 2013; Jenny et al., 2018)

Muehlenhaus, (2013) defines map composition as the visual hierarchy or decision to emphasize specific map elements. It entails determining which components or elements will be used in the representation design (Muehlenhaus, 2013; Tolochko, 2016). This method is adopted for thematic web maps from Table 5 section 2.2.3. The reason for using this approach is that it allows us to understand the most important elements for the placement of the visuals. In representation design Tolochko,(2016) defines map elements as individual components that constitute the map including those already mentioned. Many traditional print maps have been reconceptualized for web purposes and some map elements are new to web mapping and may not be available in traditional maps, yet others have been adapted to suit a digital environment. The general heuristics for map elements are to style them to have a cohesive feel between map and elements in the layout of the website (Tolochko, 2016). Below I outline possible adaptations that Tolochko suggests which will be adapted for use in the design and implementation of this research (Table 11).

Table 11: Possible adaptations of map elements for the web (Tolochko, 2016)

Map element	Possible adaptation for web mapping application
Map Title	A static title that remains in view.
Figure/mapped area	Map users can have control through zooming and panning.
Scale	With interactivity, multi-scale mapping is possible hence the map can be seen at multiple zoom levels. Zoom buttons are commonly visible map elements to allow the user to easily change scale.
Labels	Quantity and size of place name labels can change at different levels or in different views. The use of tooltips can enhance legibility and reduce visual clutter.
Map metadata	Author, data sources, projects, and other credit information does not need to be published directly in the app. It could be linked webpage, hidden menu, or modal figure
Neat lines	The map may take a full screen or distinguished from other visual elements using borders and box-shadows.
Supplement graphs	Thematic data is usually understood better by users through the inclusion of graphs or charts hence linked to thematic maps through simultaneous highlight or brushing techniques. Linked supplementary graphs or charts are not usually placed directly on top of the map but to the side or bottom panels.
Supplement information	Supplement information such as text or graphics can be displayed interactively e.g. clicks or buttons. This information can be presented as information windows or tooltips.
Legend	Allow for interaction with legend to affect map each filtering, toggling layers on and off.

Menus	It can be used to provide additional options and interactivity in menus such as search.
Help	Link to information for map users who need help in learning how to navigate through a web map.

3.6.3. Interaction Design

Interaction with the application is based on the basic principles of UX design and trying to meet the elements of User Experience (Morville, 2004). The method used in determining interactions follows the taxonomy of cartographic interaction primitives proposed in research to support the interaction design of web maps (Tolochko, 2016). An empirical study with UI/UX designers identified these primitives as objective-based, operator-based, and operand-based primitives. These are coupled with other conventional interaction techniques such as linking, brushing, details-on-demand, and multiple views. Table 12 shows some possible examples of the objective-based primitives and operator-based that would be important in this interaction design (Turchenko, 2018)

Table 12: Possible objective-based and operator-based primitives from (Turchenko, 2018)

Possible objectives for interaction primitives	Possible operators for interaction
- Identify - Locate - Distinguish - Categorize - Rank - Filter - Explore - Emphasize - Characterize distribution	- Highlight - Linking - Overview - Zoom & Pan - Filter - Details-on demand / Retrieve - Overlay

I place emphasis on the operators as they are the actions that would be required to fulfil the functional requirements for task analysis. Operator primitives are delineated into two categories enabling operator primitives and work operator primitives. Work operators allow the user to achieve the objective while enabling operators to help to initialize and save the work (Tolochko, 2016). I shall focus on work operator primitives for this research. Table 13 briefly describes some of the possible work operators which will be useful in designing the interactivity of the web map.

Table 13: Operator-based primitives for interaction design adapted from Tolochko, (2016)

Interaction operator primitives	Description
Zoom	Changing the scale and /or resolution commonly denoted with zoom in and zoom out symbols or scroll.
Pan	Changing the geographic centre of the map in the current view.
Retrieve	Request more details of a feature through direct manipulation such as clicking.

Filter	To identify features that meet one or several conditions can be through querying, toggling layers.
Search	To identify features of interest with similarity to filter how this focuses on one result while filter may produce multiple results.
Overlay	Add or remove features in the current map view such as through toggling visibility.
Linking	Linked multiple views to update visualization based on action in one view.
Highlight	Emphasize specific features through e.g. changing opacity, enlarge, or changing colour.

The principles rules and guidelines previously mentioned are used in creating the design and the choices for these are justified in the results section. The final outputs of this stage are paper sketches or low-fidelity mock-ups showing the layout, mock-ups of the web map composition, and an interactive high-fidelity wireframe that allows for interaction to show the UI/UX design. These conceptual ideas are then used in the implementation phase.

3.7. Prototype Implementation (Produce Design Solution)

This describes the implementation phase of the research project to translate the design concepts into a working prototype. The prototype implementation of the solution space is a part of the produce design solution that entails determining the functional requirements to implement based on the outcomes of the user requirement and design, knowing the most suitable technologies to use for implementing the interactive cartographic application and discussing the limitations that may arise in the implementation and future adoption of the application for end-users. I address the third objective of this research, *"To build and implement an interactive web mapping prototype to facilitate visualization of marine ES flows"*. The research questions include:

i. What are the desired functionalities and capabilities of the prototype by the end-users?
ii. What technologies and infrastructure are needed for building and implementing the prototype?
iii. What are the potential challenges or limitations in the design and implementation of the system?

To successfully execute an interactive web application, there are three main components for progressive levels of website design and implementation as discussed in section 2.3 (Garrett, 2002; Tsou & Curran, 2008). They are data and databases, web (map) servers, and map browser which covers the client-facing technologies. The components are described in a methodological order by Donohue, (2014)'s the workflow in full-stack development.

3.7.1. Prototypical Workflow and Choice of Technology

The method used in implementation is based on Donohue, (2014)'s prototypical workflow and the three major components for progressive levels of website design derived from Garrett's framework on web applications (Tsou & Curran, 2008). Employing the prototypical workflow is important as it allows one to understand the holistic picture of what may be needed in implementation. Donohue, (2014) uses it to determine the pedagogical order of understanding and implementing web mapping or how web mapping should be taught. In this research, we use it to determine the steps of prototyping that should inform the selection of web mapping technologies and decide the most appropriate technologies to use. An adapted framework for this research with possible technologies is shown in Figure 28.

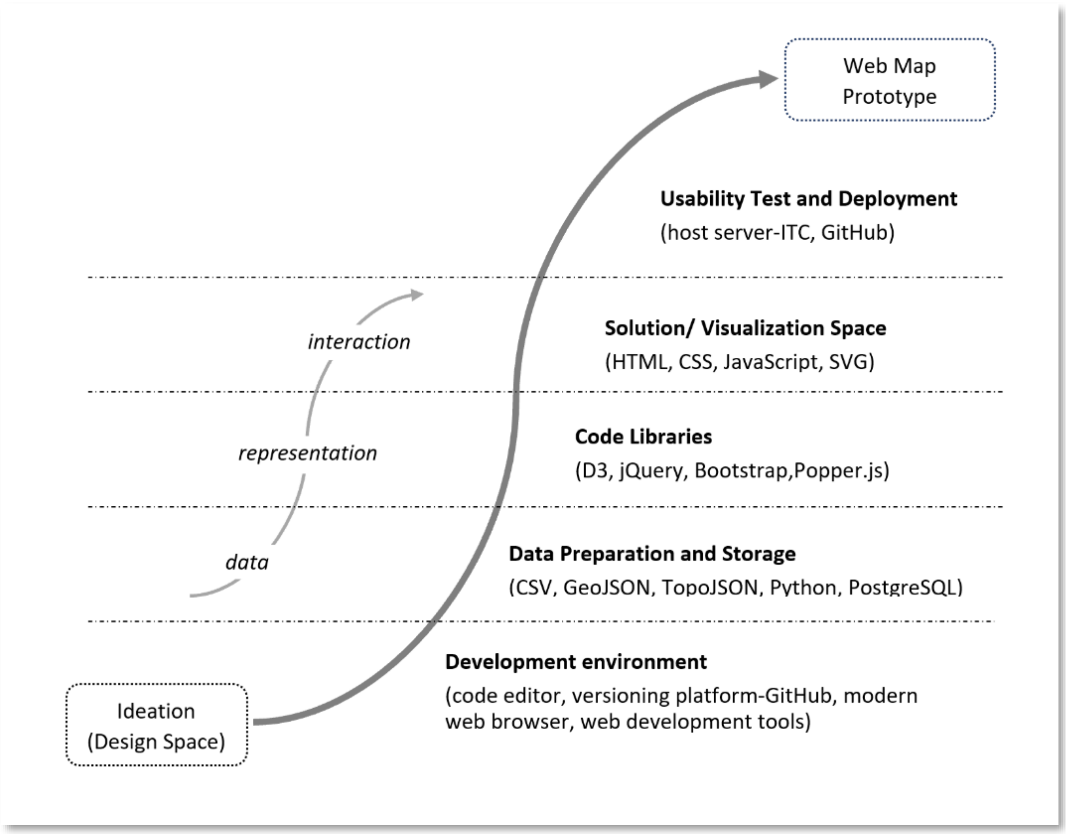


Figure 28: Prototypical web mapping workflow modified from Donohue, (2014)

The first stage in the prototypical workflow starts right after **Ideation**, or what in this context would be the conceptual design solutions produced in the design phase. The conceptual design is used to determine the functional requirements for the implementation of the prototype.

- **Development environment** involves choosing the code editor and development tools or Integrated Development Environments (IDE's). The technologies I used for this step include WebStorm and PyCharm which are both IntelliJ-based IDE's by JetBrains (https://www.jetbrains.com/). The reasons for choosing those are that they offer automatic error detection, familiarity with technology, ease of use and robustness, good navigation, and refactoring of code and support for version control. WebStorm if good for front-end development with its support in refactoring JavaScript, Typescript, and popular front-end and server frameworks. PyCharm is good for support in back-end development such as python scripting during data cleaning and pre-processing.

- **Data Preparation and Storage** phase is where we format and structure the data required for visualization in the front-end. The step by step process looks at data acquisition, pre-processing, storage, and distribution. The data formats that would mainly be considered are GeoJSON, CSV, and TopoJSON. GeoJSON is a format for encoding a variety of geographic data structures (https://geojson.org/) while a TopoJSON is an extension of GeoJSON that also encodes the topology of the data rather than discrete representations of the geometries. Python is also a key language needed in pre-processing of data for cleaning, reformatting, and carrying out routine scripting for data ingestion and curation into a database or writing restructured and reformatted data to a file. Here I also consider the storage options where PostgreSQL (https://www.postgresql.org/) is the most suitable technology for storing spatial vector data due to its robustness and ability to support spatial information as well as enabling the use of spatial functions. To manage the database a management tool for PostgreSQL that was chosen is PgAdmin (https://www.pgadmin.org/). PgAdmin is an open-source design and management interface of PostgreSQL that has useful features for creating SQL queries and manipulating data. The purpose of storing these data in a database is to perform spatial queries to join the data with spatial information and calculate spatial attributes which can then be fetched and stored in the correct file formats. Data can be temporarily stored in the database when performing cleaning, curation, and manipulation. This allows manipulation without affecting the original data files and without having to make changes manually. It, therefore, creates efficiency in data curation and manipulation. It also enables us to perform spatial queries on the data, merging, and other spatial functions to output in destination tables. However, in the implementation of the interactive application, the files are read directly from the file directory hence utilizing **file-based** storage since it is a relatively small prototype and can be easily maintained with this approach.

- **Code libraries** involve identifying the actual programming language libraries and frameworks for creating the application. I consider the need for high customization which in most cases requires libraries that allow native coding over platforms that are not easily customizable. The main JavaScript library chosen for this is D3.js as mentioned in the literature it allows for flexibility in customization of the drawn graphics, supports dynamic projection and many developers state it to be one of the most powerful libraries for creating visualizations driven by data on the web (Bostock et al., 2011). Other supporting JavaScript libraries such as bootstrap are used for quick implementation of user interface layout. The MES application has unique characteristics features which upon researching may not be supported by most off-the-shelf platforms hence for this reason D3 is chosen as the main language for implementation of the application. D3.js is also chosen over other open libraries due to its unique approach to client-side rendering and interaction. It supports the dynamic projection of linework into a wide array of map projections which is also key for flexibility in mapping such dynamic flows (Bostock et al., 2011; Donohue, 2014). When choosing a technology an important selection criteria is the online support community for questions and collaborate, further to this the online community in google groups, stack overflow, and slack is quite large and supportive and Donohue, (2014) emphasizes the importance of an open web community for learning and implementation.

- **Solution space** is the actual implementation of the interactive cartographic prototype using programming languages or front-end programming languages e.g. HTML, CSS, JavaScript, and SVG. These are regarded as a basic need for the implementation of a custom interactive web application (Donohue, 2014).

- The final step is **usability testing** and **deployment**. Research on the best platform for hosting the application, and sharing it publicly is important. If the application has so far been implemented in the local computer, public-facing web server hosting is required to avail the application through a publicly available Http link to the users for user testing. Usability testing is explained in-depth in the following section. Other than hosting the application is also important to constantly document and save versions of the work using a version control system such as Git (https://git-scm.com/) and then the final code can be shared remotely using a remote repository such as GitHub. GitHub is a remote repository for collaboration and sharing of the code work (https://github.com).

The step by step approach of the implementation based on the prototypical workflow includes acquiring the data, cleaning and pre-processing using python, pushing the data to a database, manipulating data using spatial queries, reading the data using python scripts from the database to format and restructure it in the needed format and outputting these in a file-based system. The data files are then read directly using the D3.js library and visualized to the front-end using the afore-mentioned front-end technologies. The overall workflow in the implementation is depicted in Figure 29.

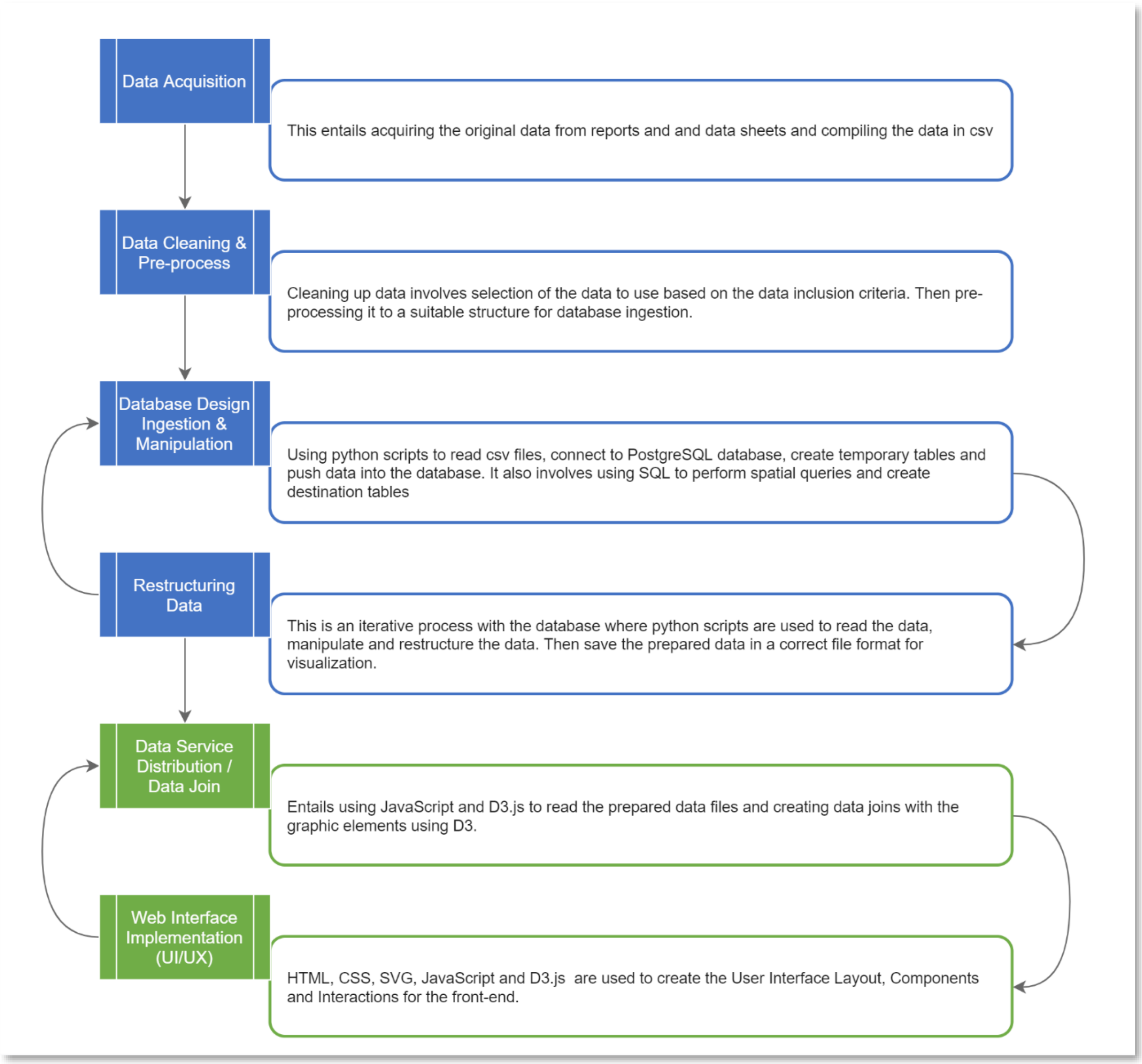


Figure 29: Workflow for the implementation of an interactive web application

The output of this stage is a preliminary web map prototype or what I refer to as the first prototype that can be used in the user testing to allow users to provide feedback on the usability of the prototype. The feedback shall then be used to adapt the first prototype to address the majority of the issues posed and the same technologies discussed here may be iteratively used in the implementation of the final prototype for deployment.

3.8. Empirical Evaluation (User Interaction and Usability Testing)

The section here describes the approach that is taken to conduct Usability Testing. The identified user, their roles, and user profiles are based on both the outcomes of the user requirements analysis as well as the produced solution. In the following sub-sections, I describe the methods chosen for usability testing, the user roles, and what shall be tested. This section seeks to answer the fourth objective of the research, *"To test the usability of the prototype application with selected end-users"*. The research questions include:

i. Which set of executable tasks will be required to assess the application's usability for the end-user?
ii. What are the potential limitations and recommendations for the improvement of the prototype for the end-user?
iii. What are the boundary conditions under which the application may be applied in other areas for future work?

The approach to reporting the usability will include *The Method* – a description of the method, evaluators/ participants, the tasks, and evaluation environment (technical/physical), *The Procedure* of designing and conducting the evaluation (e.g. questionnaires used) and data to be collected, *The Results* of the evaluation including data analysis, presentation of results and *An Interpretation* of the results and recommendations for prototype adaptation. This evaluation tests the geo-visualization web mapping product to determine how well users can achieve specific tasks to ensure that it meets the user's requirements and usability of the product. The International Standard Organization suggests that types of usability evaluations should include:

- Inspection to identify defects and potential problems.
- User observations both qualitative to identify actual usability problems and quantitative to measure user performance and responses to obtain data effectively and efficiently.
- Obtaining subjective information from users including both qualitative where problems, opinions, and impressions are evaluated and quantitative where measures of user satisfaction or perception are recorded. (Bevan et al., 2016)

3.8.1. Methods

The approaches used can be qualitative where statistical data is derived to evaluate the performance of a design or quantitative which involves obtaining design problems and user issues. Both of which shall be collected with a focus on qualitative information. Organizations and scholars describe evaluation methods in a stage-based approach where one considers at what stage of the design and implementation the testing shall be conducted such as user requirements, early design and prototyping, and test and evaluation stages (Roth et al., 2015). This research focuses on the last stages of prototyping and evaluation stages. Roth et al., (2015) also approach usability testing by considering the evaluators themselves hence grouping the methods into a broad category which distinguishes evaluators as experts, project team and target users as maintained in several UCD processes specific to interactive maps (Nielsen, 1992; Roth et al., 2015). Therefore, referencing the previously discussed categorises expert-based, user-based, and theory-based methods. This research targets end-users as well as non-experts of the application as the evaluators. The methods that may exist may fall under one or more categories depending on their use and parameters. Each of which has its own advantages and limitations. In choosing the appropriate method I consider the following questions as posed by (Bowman, Gabbard, & Hix, 2002; Roth et al., 2015):

- What are the goals of the evaluation method?
- At what stage of the evaluation should the method be used?
- In what situations is the method useful?
- What are the costs of adopting the method?
- What are the benefits of using the method when evaluating an interface?
- What are the expected results and how would they improve the interface?

The main goal of this usability testing is to quickly identify several issues with the interface design to adapt it to meet the tasks of the user. The testing is conducted in the later stages of prototyping. For these reasons, this research will collect mainly qualitative information which is necessary for a novel product at this stage. Usability testing shall be formal and involve a high-fidelity prototype where the activity is more rigorous. It comprises a collection of empirical observation data to measure usability of the design which I will evaluate against a set of both quantitative and qualitative usability goals defined. These evaluations were on an individual basis involving users and there were two iterations conducted in this research. The **first phase** focused on identifying key issues in the product and the **second phase** to measure both underlying issues and satisfaction with usability. A ***summative*** evaluation would be carried out in the first testing round of this research which refers to testing done by the actual users with a record of their observations.

The main method used is ***task analysis*** which involves studying the actions and cognitive process for which a user exhibits to achieve a task. A detailed task analysis helps understands the current system, information flows within it and the problems encountered (Maguire & Bevan, 2002). Questionnaires and interviews are part of the task analysis process (Maguire & Bevan, 2002). One of the methods suggested by (Delikostidis, 2011) which shall be used in this research evaluation is *questionnaires*. Questionnaires are a survey type user-based method that is useful when progress needs to be tracked in multiple stages/ versions of the interface (Robinson, MacEachren, & Roth, 2011; Roth et al., 2015). They can be structured or unstructured although within the framework of the usability testing. In this research, I chose to use a mix of structured and semi-structured questionnaires. The reason for this is that a more structured approach assures the compatibility of the data as the results are consistent with order and the specific purpose (van Elzakker & Wealands, 2007). The task analysis will, therefore, be based on open-ended and close-ended questionnaires.

Another method that I used in combination with a task analysis that shall be adopted here is ***expert-based think aloud***. The expert-based/think-aloud study is important in identifying a broad range of usability issues to quickly note down the most important problems and consequently adaptations to the application. This method is also very useful when project resources are limited and the tasks the interface should support are well identified. According to Nielsen, (1992) the method can be used for almost any system and is increasingly being used for practical evaluation of human-computer interfaces (Nielsen, 1992; Roth et al., 2015). It is often sufficient to use a fairly small number of test users ranging from 3 to 5 users to find a good amount of the usability problems in this method hence another reason for adopting the method in this research (Nielsen, 1992).

Nielsen, (1992) states that the methods may, however, have limitations in the real representation of usage as it is unnatural for a user to verbalize their thoughts and this will slow them down. Think aloud requires participants to explain their reasoning as they use an interface by basically verbalizing their thoughts as they solve tasks with the product. The process will involve setting up tasks for the user to test which should reflect typical serious real usage scenarios. Due to the unnatural method of verbalizing it will be important (for the experimenter) to continuously prompt the test user with questions such as "what are you thinking now?"(Nielsen, 1992). The method will involve close-ended tasks or questions and end with an open-ended session to gather information on experiences.

3.8.2. Design of Usability Testing

The tasks set in the questionnaires will assess the user profile, use content and usability. The approach of the task analysis will entail using an expert-based think-aloud method with questionnaires for project experts and other users. These sessions will finish off with an open-ended briefing to allow the participant to talk about his or her experience using the application. This open interview will be carried out to obtain qualitative information on the satisfaction of the product. Interviewing is a common technique where users, stakeholders, and domain experts are questioned to gain information about their needs which would be useful in the first evaluation phase to understand the major changes to suite the project-expert needs. Interviewing is useful when transitioning an interactive web map to a new application domain which is the case here as an interactive flow map is a novel application to MES mapping (Roth et al., 2015).

The task analysis chosen is based on the definition of the quality of use of a product. Quality in use as defined by ISO/IEC 25010 refers to system and software quality models including effectiveness, satisfaction, efficiency, freedom from risk, and context coverage (Bevan et al., 2016). Measures for the quality in use include Effectiveness, Efficiency, Satisfaction. The tasks are formulated to be able to assess the measures of quality. The New ISO suggests certain measures which I shall consider for this research and the ones I look at are mentioned in Table 14:

Table 14: Measures of attributes of usability (Bevan et al., 2016)

Effectiveness	Efficiency	Satisfaction
Tasks completed	Task time	Overall satisfaction
Objective achieved	Time efficiency	Satisfaction with features
Errors in a task	Cost-effectiveness	Discretionary usage
Tasks with errors	Productive time ratio	Feature utilization
Task error intensity	Unnecessary actions	The proportion of users complaining
	Fatigue	The proportion of complaints about a feature User trust User pleasure Physical comfort

The questions or tasks formulated (see Table 15) have different levels of difficulty, starting with the easier questions which allow for early success with the test participant and encourages them to carry on. The questions were categorized based on geographic inference as adopted from Andrienko, Andrienko, & Gatalsky, (2003)'operational task taxonomy to allow exploring different aspects of the flow map product

(Roth et al., 2015). The formulated tasks would thus explore the place and patterns such as: given where? find what? or given what? find where? These are hierarchically grouped centred on Bertin, (1967)'s level of grouping of geographic questions as described by (van Elzakker, 2004). van Elzakker, (2004) identifies 4 groups of questions including elementary, intermediate, overall, and temporal under which several tasks can be defined, and test questions can be derived. This research focuses on the first 3 aspects where temporal information is currently not part of the analysis. An example of the questions is demonstrated in Table 15.

Table 15: Example based on the difficulty level of geographic questions (van Elzakker, 2004)

Difficulty level	Geographic Question	Task	Sample Questions
Elementary	At a given place how much is there?	To estimate amounts	What is the weight of metric tons of tuna fish caught by Indonesia?
Intermediate	What is the most/least?	To quantify spatial anomalies	Which country has the highest number of fleets fishing in the WCPO region?
Overall	What relevant patterns are there?	To recapitulate the found patterns	To which regions are most of the processed tuna exported to?

Design of Experiment

A questionnaire including both open and close-ended questions was prepared, and the interview method was semi-structured. The survey was structured into 3 parts, the tester's profile, the task-based analysis questions, an interview discussion. The testers' profile questions were based on the user profile prerequisite describe in Table 6 (section 3.4.1) and it covered the following areas: Age group, education level, profession, technical expertise, domain knowledge for ES, and case project knowledge of WCPO. An example of these profiles can be seen in Figure 30.

User	Profile		Results
TP 1	Age group		35-50
	Highest Level of completed education		Doctorate
	Educational Background		Marine Policy
	Main occupation		Director of Ocean Policy Program, Nicholas Institute for Environmental Policy Solutions.
	Technical expertise	Experience using maps	No
		Familiarity with interactive maps and web applications	No
		Familiarity with interactive map functions	No
	Domain Knowledge	Are you familiar with Marine Ecosystem Service Flows?	Yes
	Use Case knowledge	Familiarity with the WCPO fisheries and the Pacific Possible Project reports?	Yes
		If involved in what capacity or work?	Researcher for a series of reports on Tuna fisheries.

Figure 30: Example of a Test Participant use case profile

The questions for task analysis were focused on testing efficiency, effectiveness, and satisfaction. The questions were also categorised by geographic level of difficulty as described in the methodology where testing would be delineated based on elementary, intermediate, and overall levels of information (Andrienko et al., 2003; van Elzakker, 2004). To test efficiency and effectiveness close-ended questions were used. While for satisfaction both close and open-ended questions were used. Efficiency is the resource expended to achieve a task or goal and hence in this case was measured in time taken to achieve a question along with difficulty level. Effectiveness referring to the accuracy of achieving a goal was measured by the accuracy to complete a task or achieve the goal i.e. if the user got the answer wrong, right, or right with help. To answer the research the question *"which set of executable tasks will be required to assess the application's usability for the end-use*r", a set of questions were formulated based on these methodologies proposed and are presented in Table 16. A sample of the questionnaire created for the 1st round of user testing is attached in Appendix A.

Table 16: Usability Testing Task-based Questions

Usability measure	Difficulty Level	Task	Geographic Question	Sample Question
Effectiveness (accuracy and completeness) & Efficiency (time resource and difficulty)	Intermediate	What is the most/least?	To quantify spatial anomalies	1. What is the largest benefit type of Papua New Guinea with country code PG?
	Elementary	At a given place how much is there?	To estimate amounts	2. What is the weight in % share distribution of tuna fish caught by Micronesia with country code FM as a resource owner?
	Intermediate	Is that geographic object linked to other objects?	To encounter spatial linkages	3. What countries does Taiwan export tuna fish to for processing?
	Overall	What relevant patterns are there?	To recapitulate the found patterns	4. Which regions do most countries export processed tuna to for consumption (market)?
	Intermediate	What is the most/least?	To quantify spatial anomalies	5. Which is the largest processing location of fish by weight in metric tons?
	Intermediate	What is the most/least?	To quantify spatial anomalies	6. Which country has the highest percentage of fleets fishing in WCPO?
	Elementary	At a given place, what is there or how much is there?	To identify objects or estimate amounts.	7. What is the main way that China benefits from tuna fish of the WCPO region?

	Overall	What relevant patterns are there?	To recapitulate the found patterns	8. Name one county which processes tuna and consumes it domestically (processing to market), closed-loop interactions.
Usability	**Measure**		**Sample Question**	
Satisfaction	Discretionary usage & Satisfaction with features		1. Is the visualization misleading/ ambiguous e.g. does it convey confusing information?	
	Satisfaction with features		2. Is the choice of colours suitable?	
	Feature utilization & Discretionary usage		3. What is the best use of this visualization?	
	Overall satisfaction		4. How easy is it to use the visualizations?	
	Overall satisfaction		5. Which visualization did you find more straightforward, easy to understand?	
	Feature utilization		7. Do you have any suggestions for improvements?	
	Overall satisfaction & Feature utilization		7. Do you have additional comments, are all functions of the application useful and what could be removed?	

Sampling

The sampling method chosen was gatekeeper sampling method (Jp & Oppong, 2013; Rühringer, 2018) which means that the access to test persons was provided through key contact person who is involved in the project. Then the snowball method was also applied where the contact person within the WCPO's Pacific project would further suggest potential participants (Baxter et al., 2015). Recruiting test participants took place during April 2020 through sending invitations via email. The targeted number of participants would be 10 people to ensure that at least 4 people respond or are willing to participate.

The evaluation shall be based on the previously derived profiles from the user requirement analysis. The chosen roles identified therefore include Policymakers at global/regional or national level, administrative users at the national level, Fisheries Management at national & sub-national, the scientific community e.g. Ecosystem / GIS/ Marine researchers, Local experts, Fishermen, or coastal communities. The evaluation tested both experts in the roles mention as well as non-experts in any field. In many system evaluation processes, adequate useful feedback to assess the usability of design can often be provided by a small number of expert reviewers (Nielsen & Mack, 1994; Tsou & Curran, 2008). According to Nielsen, (1994), 3-4 testers are enough participants required for the think-aloud method as they usually uncover a large number of usability issues. As such for this research the **minimum** number of test participants acceptable shall be 4 with at least 1 expert.

Evaluation

Based on the described methods the evaluation will be carried out by first setting the goals required to be achieved, then the tasks and related questions that shall be categorized by the measure of usability as well as the difficulty level. These tasks shall evaluate effectiveness, efficiency, and satisfaction at a visual level, data level, functional and task-based level. The design presented for evaluation in chapter 4 will involve:

1) Formulation of Hypothesis – what is to be evaluated or goals to be achieved
2) Design of experiment – based on the design of the sample question described in methodology (Table 16).
3) Execute experiment – to describe users and how the experiment was conducted e.g. how long
4) Analyse the results.

3.8.3. Adaptations and Final Prototype Implementation

Usability testing is an iterative process. In this research, we conduct a two-round usability testing. The first round employed task-based analysis and focused on uncovering usability issues with a minimum target of 4 test participants. The second round however focuses on satisfaction testing to determine if the issues that were previously uncovered still exist or were resolved and to also test the overall satisfaction of the user. Measures of satisfaction will include testing for overall satisfaction, satisfaction with features, and the discretionary usage of the application (see Table 14). Ideally, a second user testing with all users would be preferable however due to time and availability of participants I opted to conduct an evaluation with one project expert where the user would give feedback on the final prototype.

The method used is a formative online survey through a short interview session. The previous method in the first round of testing was summative which means that the metrics reflect a quantitative data collection of observations by end-users. A formative survey, however, records information that is of a qualitative nature to identify perceptions, confusion, or logic in the functions that exist, confront thought process of decisions in the implementation, and determine the usefulness and simplicity of the product (UX247, 2017). Formative surveys may be carried out by experts. The approach for reporting this in the results will include the design of the interview questions, execution of the interview, and synthesis of the results. The overall feedback from the second testing would inform further discussion on constraints and limitations of the application, recommendations for future work, and its reproducibility in other domains.

4. RESULTS AND DISCUSSION

This chapter describes the outcomes of the use and user requirements analysis(section 4.1), provides functional formative requirements for the web design, the geo-visualization low-fidelity prototypes in terms of sketches and final design concepts based on the design guidelines (section 4.2), data acquisition, pre-processing and restructuring and prototype implementation (section 4.3) and first empirical evaluation, prototype adaptation (section 4.4) and finally the second round of formative evaluation and deployment (section 4.5). The outputs of each section address the objectives in this sequential order related to the discussed methods.

4.1. Use and User Requirements

The methods described in the previous chapter are based on information derived from previous research on the Use and User requirements of ES Maps by Rühringer, (2018). The research describes the users and use purpose for map users and mapmakers, the derived usability issues, and the design recommendations. This then informs formative goals/purpose and needs/requirements for the Use case chosen. The derived user requirements are the outputs explained here based on the first research question of the first objective "*What are the requirements by the end-user for the system based on analysis of user research to communicate marine fish flows for the WCPO region*?"

4.1.1. Identifying Users and Use Purpose

Rühringer, (2018) analysed different sets of users at different decision-making levels and identified various purposes for which ES maps come into practice in their work. She identified both map-users and mapmakers, however, in this research what is of importance is the map-users perspective to derive their needs. In the map-users context, Rühringer, (2018) proved true that most policy officers at the EU level are well informed and familiar with ES concepts and maps and the EU Biodiversity Strategy, albeit this may have been biased based on the selected users. Nonetheless, the findings emphasised the need to have a clear map that is simple and precise. At national level users are concerned with other national policies and pointed out that ES maps are only partially used for decision making and highly depend on expert-based knowledge and experience as well as other visualization purposes. The users here also dominantly used static screen maps or paper maps and did not work much with interactive maps (Rühringer, 2018).

At the EU-level the decision-making process was supplemented by maps, however, users at the national level mainly pointed out laws or expert knowledge as the main factor guiding their decision-making process. At all levels policy requirements and other visuals also influenced decision making. The maps were dominantly used in the static desktop environment over interactive cartographic systems (Rühringer, 2018). Rühringer, (2018) found that the intended use purpose and actual purpose did not differ much i.e. between mapmaker and map-user, however, observed that some of the cases were very generic due to the lack of awareness on the specific application of the maps. In comparison, she concludes that the use purposes were more policy-related at the EU level and get more specific at the lower administrative levels. I borrow from the outcomes of her work some of the intended use purposes at the different levels and highlight in Table 17 only those that are related to this research

Table 17: Summary of Users and their Use Purpose adapted from (Rühringer, 2018)

Users	Purpose (from general)
Global / Regional level (Policymakers Scientific Community)	- To inform decision and policy development, impact assessment for policy success. - To raise awareness & communicating ES
National Level (Policymakers, Administrative users Scientific Community)	- To support policy development and managerial decisions - To monitor, manage and assess risk - To provide spatial information
Sub-national level (Fishery Management, Local experts, Fishermen, Scientific Community)	- To assess future management scenarios and trade-off analysis - To monitor resources - To support management decisions (practice and policy) - For educational purposes and raising awareness

One of the main recommendations of Rühringer, (2018)'s work is that the map creation should be done with a specific user in mind. In this case, I focus the demonstration of the interactive web map on the Pacific Possible project on Tuna fisheries for the Western and Central Pacific Ocean (WCPO) region. The users identified are derived from Table 17 as well as from the case study description. Reflecting on the use case the key general user roles identified would be:

- Policymakers at regional/global levels & national levels
- Administrative users such as at national level such as government resource managers
- Fisheries Management at the sub-national level
- Scientific community; GIS analysts, ES and Marine researchers
- Local experts / Fishermen/ coastal communities

Policymakers at the national level would be key in decision making and implementation of some of the strategies outlined in World Bank and Nicholas Institute, (2016) such as hard fishing efforts. Policymakers at the regional level would be important for the regional cooperation around shared resources. Managerial users would be significant as one of the outlined strategies of investments in skills and capacity building of tuna fish managers (World Bank and Nicholas Institute, 2016). The decisions for sustainable use of resources and investments affect the fishermen, hence, it is important to have the inclusion of coastal communities where feasible.

The Pacific Possible project focused on 3 main objectives which included describing the current economic contributions from resources as the baseline information, the expected changes in direction of indicators and a best-case future scenario based on policy strategies and expected change in key drivers (World Bank and Nicholas Institute, 2016, p. 14). The objectives are dependent upon the implementation of the policy decision in the Regional Roadmap for Sustainable Fisheries. From this, we can assume that a crucial user role in this research is policymakers at global or national levels. Therefore, policymakers at the global level (e.g. marine policy) and the scientific community users (e.g. ES experts or GIS experts), as well as non-experts, are chosen for purpose of scenario design (4.2) and usability testing (section 4.4).

4.1.2. Derived User Requirements

Reflecting on the use and use purposes, and based on the objectives of this report it can be deduced that the general roles of the personas identified and their user requirements are as summarized in Table 18.

Table 18: Identified User roles, purpose and needs for WCPO Case

Users	Purpose (from general)	Needs/Requirements
Global / Regional level (Policymakers Scientific Community)	To inform decision and policy development, impact assessment for policy success. To raise awareness & communicating ES	- Develop and support regional policies for fisheries (e.g. Regional cooperation and shared resources in Pacific Island FFA) - Support Conservation and Management decisions and policies e.g. The Western and Central Pacific Fisheries Commission (WCPFC) - Communicate and raise awareness on the fishery beneficiaries
National Level (Policymakers, Administrative users Scientific Community)	To support policy development and managerial decisions To monitor, manage and assess risk To provide spatial information	- Guide national fishery commissions - Design and implement national fish policies - Monitor marine biodiversity and habitats - Implement sustainable fishing strategies (e.g. hard fishing effort)
Sub-national level (Fishery Management, Local experts, Fishermen, Scientific Community)	To assess future management scenarios and trade-off analysis To monitor resources To support management decisions (practice and policy) For educational purposes and raising awareness	- Raise awareness to local communities on sustainable fishing and use of resources - Inform economic future scenario analysis - Monitor fish resource - Capacity building for managers (e.g. tuna mangers)

Ideally, the application should meet most of the needs mentioned in Table 18, however for purposes of design, implementation, and usability I limit our focus on what I consider most important for the case study chosen which aligns with *policy and decision making* and *communication of baseline information*. In that regard for design conceptualization and empirical evaluation I formulate scenarios which focus on the following user requirements:

- Communicate and raise awareness on the fishery beneficiaries.
- Support regional cooperation and shared resources policies among Pacific Island Member states.
- Monitor marine biodiversity and habitats.
- Support policy and decision making on sustainable fishing practices
- Communicate and raise awareness of the fishery demands/benefits.

4.1.3. Map Recommendations and Usability Issues based on ES Users' Requirements

In all levels identified by Rühringer, (2018), various issues or influencing factors were found including data availability, resolution, data quality, missing methodologies, expertise, temporal restrictions, and limited manpower. Rühringer, (2018) also analysed and summarised the usability issues that arose from various maps noted by the different levels of users. An outline of some of the issues that I specifically take into account in the design stage is described in Table 19.

Table 19: Usability issues found by users of ES maps Rühringer, (2018)

Attribute	Usability Issues
Colours and Colour scheme	Colour-blindness (visual impairment) Difficulty in interpreting colour scheme o
Legend	Too much text Too many categories in the legend Units of legend
Description and Content	Missing descriptions Uncertainty in map content Illegible font (too small) Small map elements
Tile	Missing title
Personal knowledge	Uncertainty about scenario assumptions A contradiction of map content with the knowledge
Map labels	Missing map labels

From the usability issues, Rühringer, (2018) provided recommendations for a general guideline for map design in cartographic context as well as for ecosystem service maps. Table 20 summarised those which I use in the design of the application.

Table 20: Recommendations for usability issues derived from Rühringer, (2018)

Issue	Recommendations
Colour scheme and Visual impairment	Use distinguishable colour combinations for variations of colour-blindness e.g. red and blue, red, and purple, orange, and blue, etc. (Rühringer 2018, Brewer, 2016: 169). Use a colour scheme that matches the structure of the data e.g. sequential data should be visualized with a sequential colour scheme (Rühringer 2018; Brewer, 2016; Kaye et al., 2012).
Legend units, colour, and categories	Include units if applicable Diverging/sequential colour scheme: Use a maximum of five hues of the same colour (Peterson, 2009). Qualitative colour scheme: Use a maximum of 10-12 different colours (Peterson, 2009).
Map content	Include map title to describe the map purpose at top/bottom Add explanatory description explaining the map content Ass necessary labels to help understanding Legible font size of map description, map labels, legend labels, and title

4.2. Conceptual Design

This section describes the design choices, guidelines, and best practices that have been implemented in the research based on the chosen methods. The method for creating the low fidelity prototypes (section 3.6) includes employing a scenario-based approach for the retrieval of application functions. From these requirements, interface design guidelines, UI/UX design principles, and other fundamental guidelines are then used in the designing of the navigational layout of the web applications. Graph principles for flow maps and OD data as well as Cartographic design principles and best practices are used for the design of the cartographic map composition. This section will describe the scenario-based results and application requirements, the web layout design, and the cartographic map composition design. I, therefore, address the second research objective; "*To design an interactive web mapping application for the visualization of marine ES flows*".

4.2.1. Scenario-based Design

In this research we emphasize a generic approach to building a tool that can be adapted to serve different levels and types of users; however, for the design and implementation in the research, we choose to focus on case study experts or users mainly in fisheries management, ecosystem services or users who are part of the World Bank Pacific Possible Project. Policymakers, researchers, and project experts who would use this communication tool to convey information to other users are hence the targeted choice in the scenario-based design. This informs the persona profiling that would be used in ideating 2 case-based scenarios for the purpose of the design stage (Table 21 and Table 22). The outcomes then inform the application's functional requirements. The scenarios describe the persona profiles. Using the method of task identification explained in section 3.6.1, such as Bertin's reading levels and Shneiderman's Visual Information seeking mantra, several tasks are also identified under each goal with different levels of geographic difficulty.

Table 21: Use Case Scenario 1 persona TP1

User Profile/Persona	**Age group:** 31 - 40 **Highest education:** University degree (MSc.) **Educational Background:** Economics **Profession:** Economics researcher at the World Bank **Map use experience:** Somewhat experience **ES maps knowledge:** Little to basic knowledge of ES concepts and maps basic knowledge of working with ecosystem service and its concepts. **Digital skills:** Adequate computer basics and digital interactivity. The user has previously interacted with interactive maps however not in the context of ecosystem services. **Role:** Research scientist at the regional level **Use case relevance:** Project expert in the Pacific Possible Project
Use case scenario / Background	Test participant TP1 is an economics scientist in World Bank working in part under the Pacific possible project. The user would like to understand and communicate the value importance of tuna fish and the distribution of this resource in different countries/regions. As an economist TP1 would like to know the trend in the value supply chain and how countries are related or linked in the distribution of these resources.

Use Purpose	1. To provide spatial information for communication and awareness of the countries that benefit most from tuna at each stage of the value supply chain. 2. To present the relationships of the resource between countries for the regional corporation and policy development.
User Needs/Requirements	Communicate and raise awareness on the fishery beneficiaries. Support regional cooperation and shared resources policies among Pacific Island Member states.
Data needed for completing tasks	- Weight of tuna fish harvested by resource and fleet owners - Weight of tuna fish processed - Percentage of tuna exported to different countries
How the user will interact with the application	TP1 would like to have a general view of beneficiary distributions in each segment. TP1 should be able to find out distribution per different types of benefits (resource, harvest, and processing). TP1 should also be able to discern more in-depth information per region and see the relationship between that location and other locations.
Geographic Questions	1. What is the most/least? 2. What relevant patterns are there? 3. What is the spatial distribution of that object?
Related Tasks required to be solved	- What countries experience the highest benefits of tuna as resource owners, fleet owners, or processing plants? - To which locations are most tuna fish exported for consumption? - From what countries does Europe receive processed tuna fish? - What is the distribution of fleet owners of tuna fish across the globe?
Task Requirements	- Visualize an Overview of the distribution of beneficiaries in each segment. - Visualize the flow of relationship in spatial interaction to/from a location - Search by region/country/segment to find an attribute in the value and weight of tuna resources. - Filter data viewed by beneficiary type and on-demand relationships.

Table 22: Use case scenario for persona TP2

User Profile	**Age group:** 41 - 50 **Highest education:** University degree (Ph.D.) **Educational Background:** Marine Science **Profession:** Marine scientist in the Pacific Possible Project **Map use experience:** Somewhat experience **ES maps knowledge:** Advanced knowledge of ES concepts especially MES as well as various guiding policies and frameworks that exist both at regional and national levels. TP2 has also used ecosystem service maps in conveying information and in decision making. **Digital skills:** Adequate computer knowledge and digital interactivity. The user has previously interacted with interactive maps however not in the context of ecosystem services. **Role:** Research scientist at the regional level **Use case relevance:** Project expert in the Pacific Possible Project

Use case scenario / Background	Test participant TP2 is a scientist who has knowledge of the Pacific possible project. The user would like to the of tuna fish resource distribution and its value to the pacific island countries. TP2 is more concerned with habitat conservation and biodiversity and as such is focused on understanding where the demands for the tuna resource comes from, how they are linked, and the magnitude of these demands to determine the pressures on the marine ecosystem for WCPO region.
Use Purpose	1. To monitor, manage and assess risk on biodiversity 2. To monitor resources 3. To provide spatial information on ES demand/benefits
User Needs/Requirements	Monitor marine biodiversity and habitats. Support policy and decision making on sustainable fishing practices Communicate and raise awareness of the fishery demands/benefits.
Data needed for completing tasks	- Weight of tuna fish harvested by resource and fleet owners - Weight of tuna fish processed - Percentage of tuna exported to different countries
How the user will interact with the application	TP2 would like to have a general view of demand distributions in each segment and see how the demand triggers flow from one location to another. TP2 should also be able to discover more in-depth information about demand such as the magnitude in weight and value from regions as well as see the relationship between the location.
Geographic Questions	1. At a given place, how much is there? 2. Is that geographic object linked to other objects? 3. What is the spatial distribution of that object?
Related Tasks required to be solved	- What quantity of tuna fish is processed by country X? - Which countries does country Y export tuna to for processing? - What is the distribution of tuna fish resource owners across the globe?
Task Requirements	- Determine the value in the monetary and weight of tuna resources being harvested in a location. - Visualize an overview of the distribution of beneficiaries in each segment. - Visualize the flow of relationships in spatial interaction to/from a location.

From the above 2 case scenarios, a derived summary of the application requirements includes:

- Visualize an overview of the distribution of beneficiaries in each segment.
- Visualize the flow of relationship in spatial interaction to/from a location
- Search by country/segment to find an attribute in the value and weight of tuna resources.
- Filter data viewed by beneficiary type to focus on specific relationships
- Determine the value in the monetary and weight of tuna resources being harvested in a location.

To address application requirements the following functionalities or actions are required: visualize an overview of information and relationships, search/find information, interactivity, filter, and query. These are being implemented using several components in the application to meet the tasks identified (Table 23).

Table 23: Functional requirements of the application to be implemented in the design space

Functionality	Components	Task Identification (tasks and sub-tasks)
Visualize Information	Pan Zoom in/out Full extent	*Overview Information* - Locate area - Zoom to adequate scale - Visualize overview of spatial interactions (flows)
Search / Find Information	Search box, Description panes (About and Help)	*Find Information* - Browse metadata/description about application - Browse to help on using the application *Search Data* - Search information in the search box such as country to see more details
Interactivity	Map pane, Toot tip Pop-ups Magnifying glass Brush Sankey diagram Bar graph Animated flow map Choropleth map	*Manipulating Map* - Zoom to the area of interest - Pan across map plane - View the whole extent of the map sheet - Switch between segments e.g. resource-owner, fleet, processing *Interpreting map* - Hover or click to show more information. - Click to filter flow information - The use tooltip for more information. - Magnify to interactively visualize small islands. - Brush tool to filter by highlighting flows or countries. *(Non-)Spatial Interactions* - Overview of flows maps in the map pane - Interactive Link with Sankey diagram and bar chart - Animated flow line *Trends* - Overview of choropleth maps in the map pane - Interactive link with graph
Filter	Navigation pills Search box Checkbox Brush	*Manipulating data* - Use zoom to visualize different scales. - Checkboxes to switch between beneficiary types in datasets - Search box to see the information of a specific location. - Brush tool to filter flow lines on hovering and links
Query	Dynamic Query (Search)	- Query dataset of interest such as country/segment. - Allow zoom and highlight of the searched item.

4.2.2. Representation Design

In representation design, we describe the web map layout and map composition. The steps in reporting will start with low-fidelity prototypes to high-fidelity prototypes and design justifications for web layout and web composition. Centred on the application functional requirements this application will include 4 types of graphics:

1. *Flow map* which, as described in the literature, is one of the most suitable map types for showing spatial interactions and relationships in flows.
2. *Choropleth maps*, which would be useful in comparing which countries benefit from tuna by beneficiary type and by what magnitudes.
3. *Stacked bar chart*, which would act as a supplementary graphic to visualize the beneficiary by countries and allow for comparison with other countries by beneficiary type.
4. *Sankey diagram*, which is another supplementary graphic that easily gives a view of the flows from one spatial location to another where the geographic attribute is not explicitly visualized but implied by the geographic country names. This is useful when linked to the flow map to see the actual movement or relationships if the flow map countries are very small. It is also a good alternative to capture information of different spatial scales where aggregated regions or trans-national levels cannot the visualized in the same resolution with the country-level in the map.

Web Map Layout

Paper Sketches were used to create the conceptual ideas for the web layout placement with all the components. The initial design included two options as in Figure 31. Though, option 1 proved to be less visually cluttered. Also, according to Occam's Razor' Law applied to UI design, the simplest solution is always the best (Yablonski, n.d.), hence I opted for version 1. In addition to graphic visualizations, the supplementary information in form of menus may be added to enable users to learn more about the application and perform extra functionalities such as search. Therefore, there are 5 main components considered in the initial web map layout and they include:

1. Map Panel – would contain all the maps i.e. flow map and choropleth maps
2. Graph Panel – a supplementary stacked bar chart
3. Sankey Diagram Panel – a supplementary flow graphic
4. Data/Information Menu – supplementary information such as about, help, metadata, and search.
5. Title and secondary components.

The initial design concept has a splash screen as the welcome to describe the application and then an overview of the map panel, Sankey and graph panel, and title section as in Figure 31. However, the splash screen was removed in implementation for quick loading. The initial design concepts were then visualized in a wireframe mock-up using MockFlow as shown in Figure 32. Here general visualization principles such as balance, hierarchy, dominance, and similarity were considered.

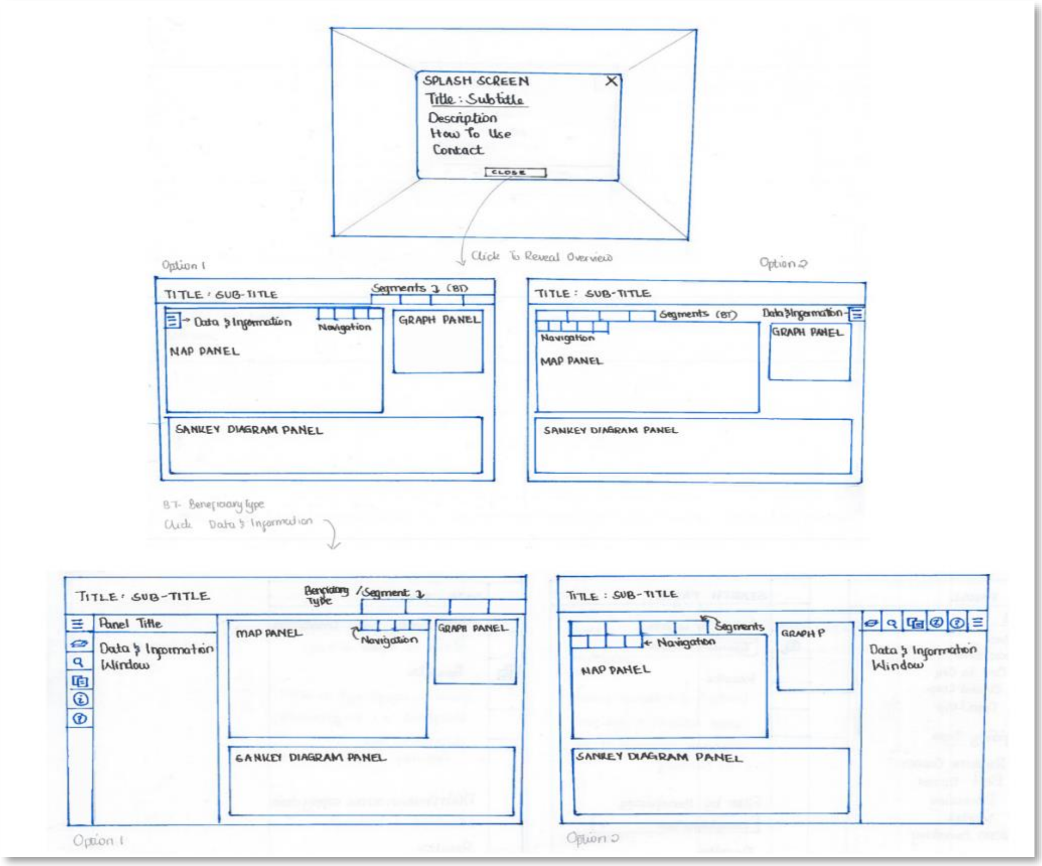


Figure 31: Hand sketches of concepts for the web application navigational layout

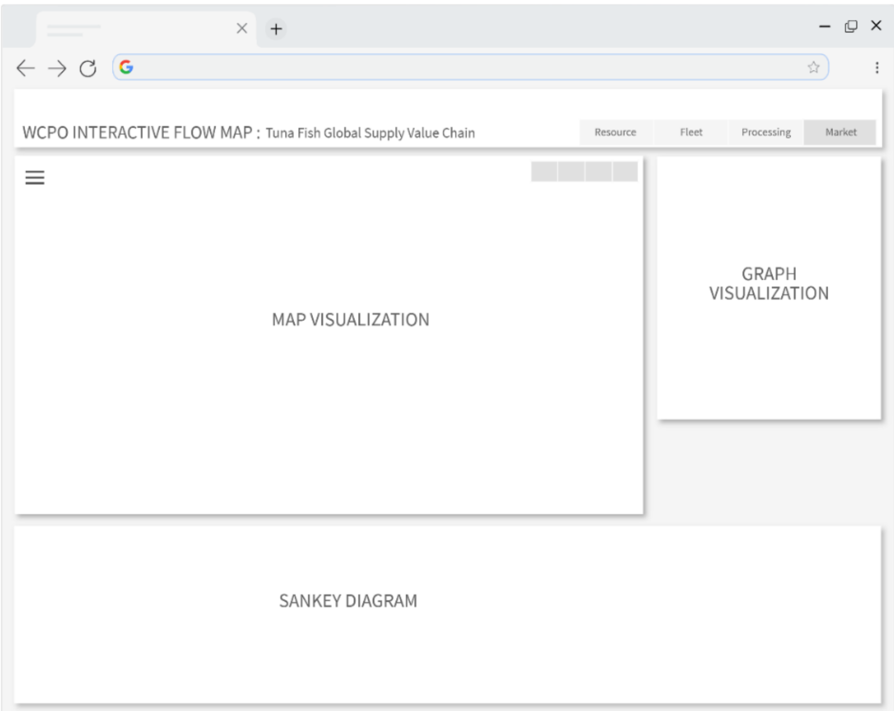


Figure 32: User interface design layout of the web map components

Web Map Composition

This refers to the actual data or elements used within the web application. Based on the system requirements the user first sees an overview of the flows, bar graph, and Sankey diagram. The elements in the interface allow for interactivity to visualize more information.

Low Fidelity Prototype

The first ideation step involved hand-drawn sketches of possible implementations of the map elements to be considered in the final prototype. The sketched layout also shows the menu window with various data menus. These panels included layer, search, information, and help. The sketches were then translated into mock-up designs (Figure 33). MockFlow was used to provide a general visualization of the navigational component layout in the web browser and data layouts to have a general idea of placement before proceeding to implement a high-fidelity prototype (Figure 34).

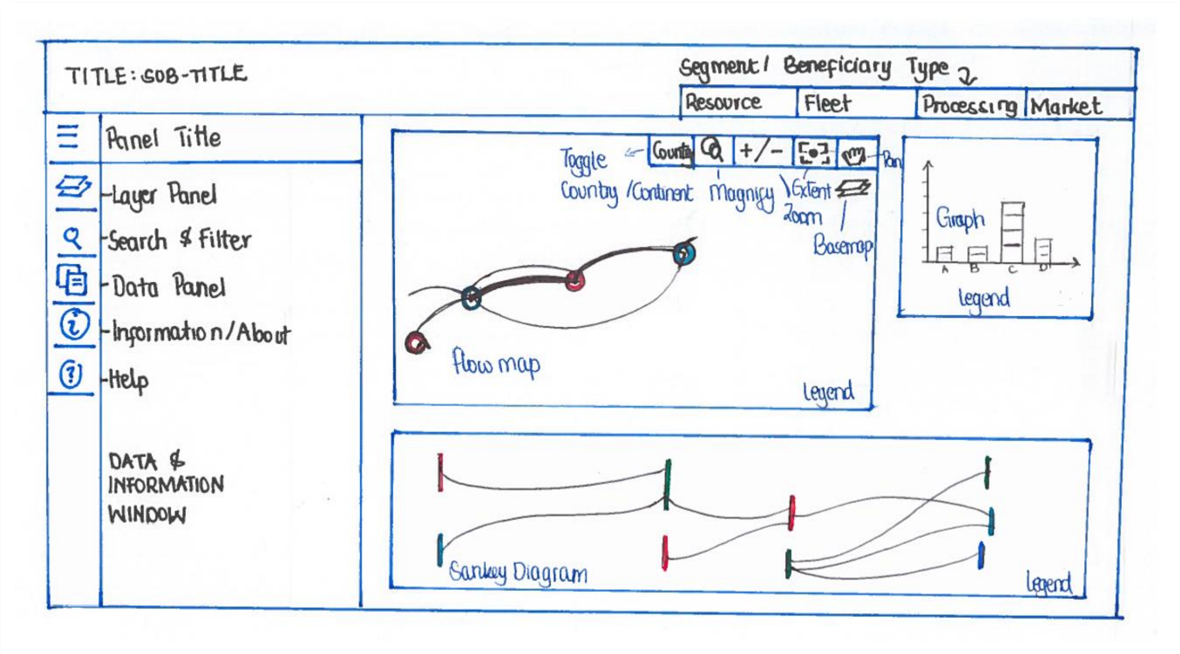


Figure 33: Sketch of the map composition elements and information panel

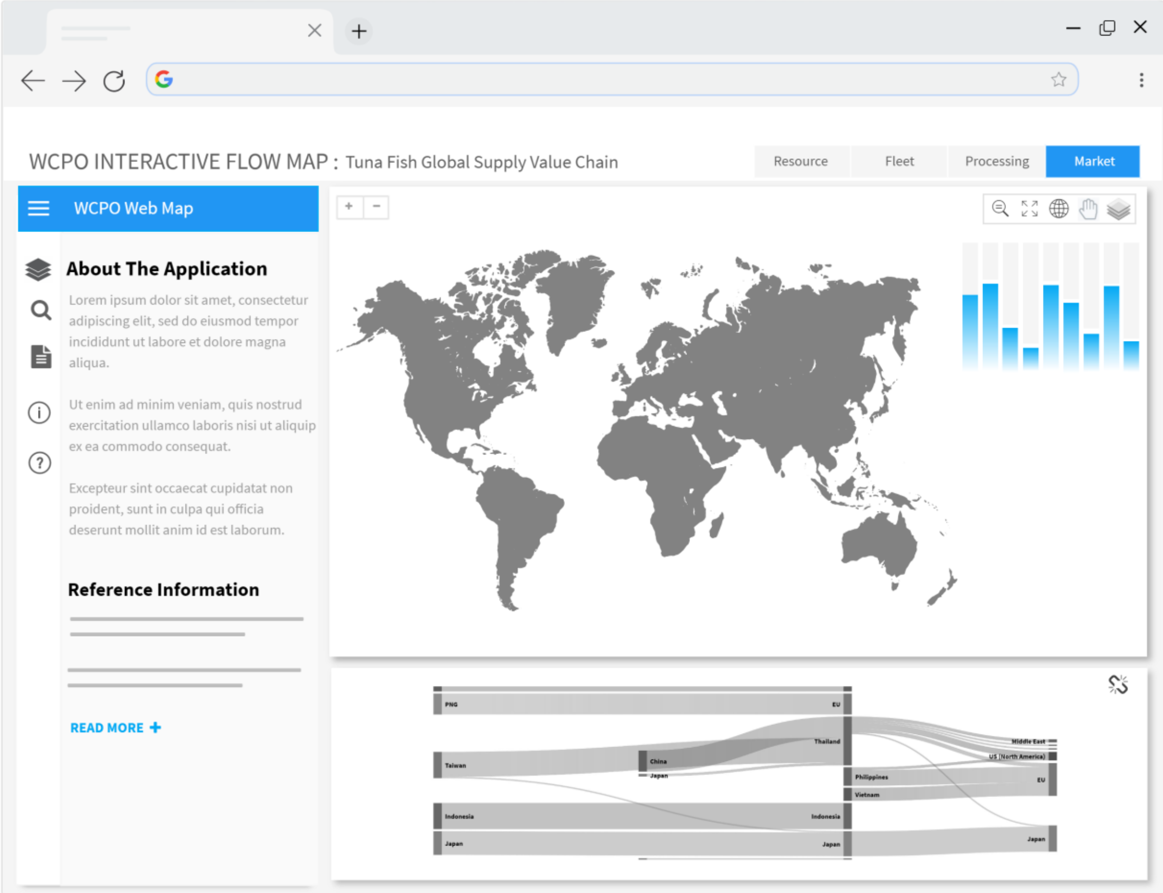


Figure 34: Low fidelity prototype concept of web map layout and composition

High Fidelity Prototype

High fidelity prototypes are mock-ups that are closer to the look and feel of the actual product. It involves careful thought and deliberate choices in designing based on set graphics principles. These visual mock-ups are used to communicate to experts or users, for feedback on whether the design meets most of the requirements. Here I conceptualize the UI as close to reality including choice of colours, fonts, sizes, and placement.

AdobeXD was used to further translate the low fidelity mock-ups into high fidelity visual mock-ups. The possible adaptions of map elements for the web provided by Tolochko, (2016) such as title, mapped area, scale, labels, neat lines, metadata, supplementary graphs, and information, legend, menus, and help were implemented and the description for possible adaptations of the implementations are described in Table 11 of the methodology (section 3.6.2). Figure 35 demonstrates this at an overview level.

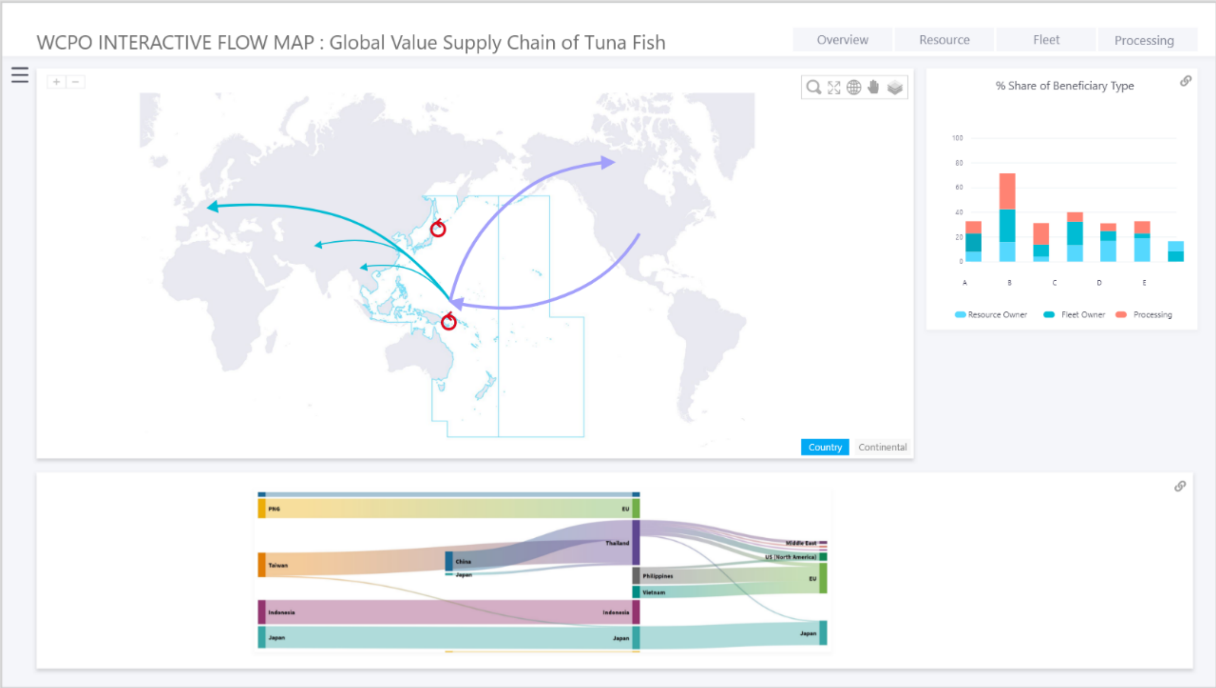


Figure 35: High fidelity User Interface layout of Overview

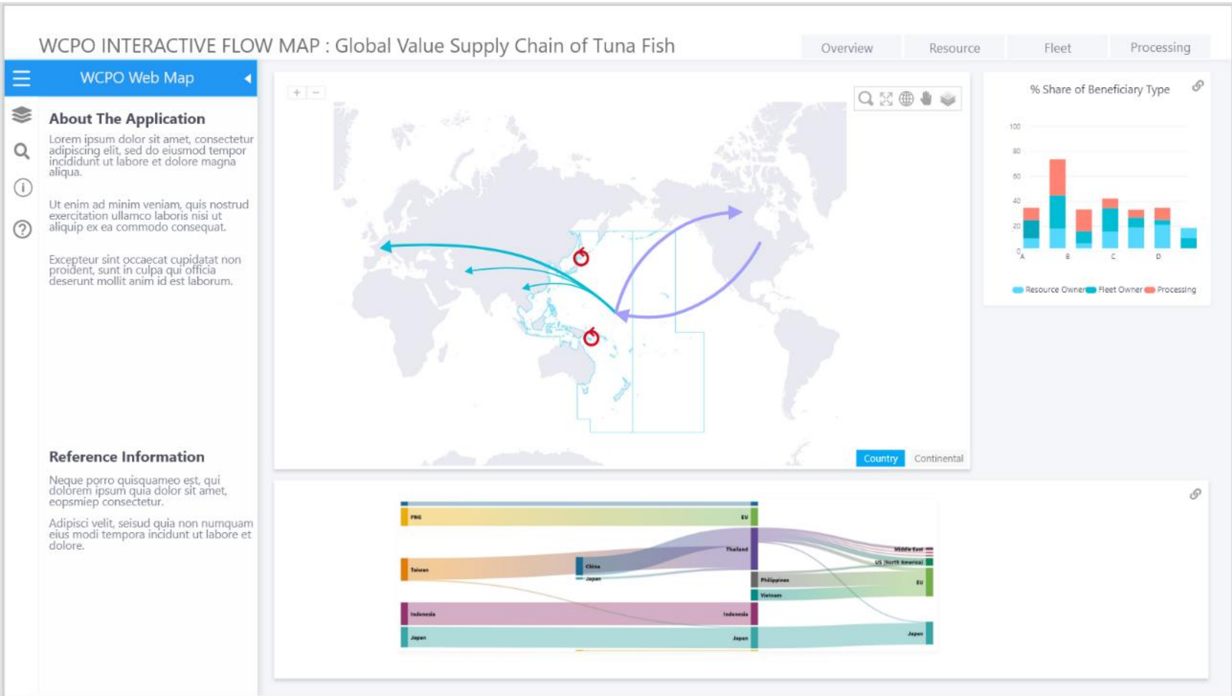


Figure 36: High fidelity User Interface wireframe with information window

When the menu bar icon is clicked the information window opens which contains the menu items (Figure 36 and Figure 37). The initial concept had 6 menu items which included a data panel. However, in this phase of ideation, I chose to have only 5 panels to reduce the memory load on the number of items the user must interact with and remember. The supplementary information aids users in better understanding the project and navigating through it. The data layout view, therefore, includes the following five components:

- About panel: which describes the application, its purpose, and use.
- Legend panel: contains an interactive legend that changes based on the map displayed.
- Search panel: allows for dynamic queries of the information to display information on specific countries and their beneficiary type with a graph of the weight in metric tons.
- Help: provides the user with a description of how to navigate the application.
- Information window: Reference information on the metadata and sources of the data used.

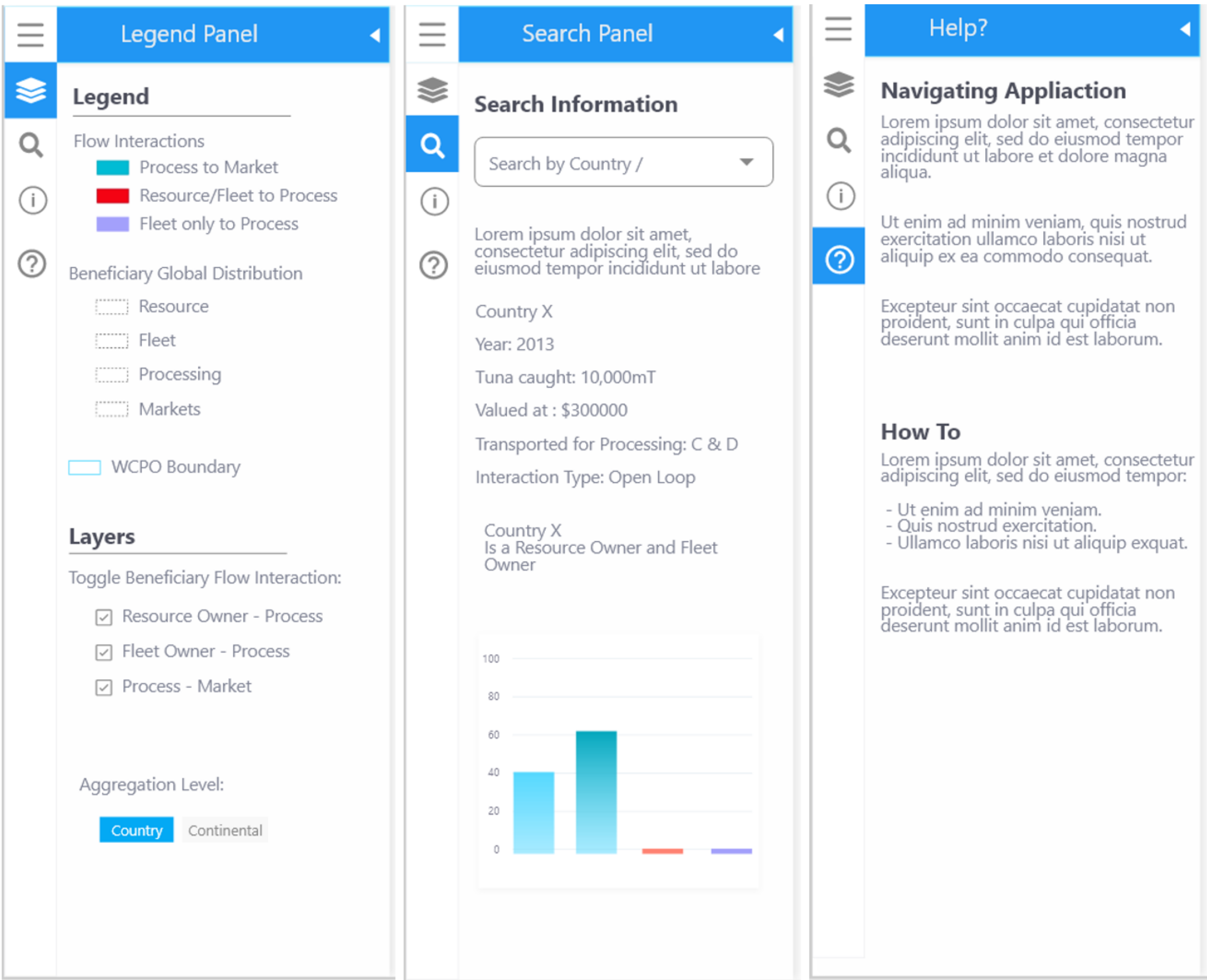


Figure 37: Information Panel menus for map composition UI design

The map panel is a dynamic panel that is also used to display the other map types for distribution by beneficiary i.e. resource, fleet, processing. Choropleth maps were chosen based on the cartographic design to be the most suitable to represent the type of data described which is quantitative, discrete, and relative(Alkema et al., 2013) see Figure 38.

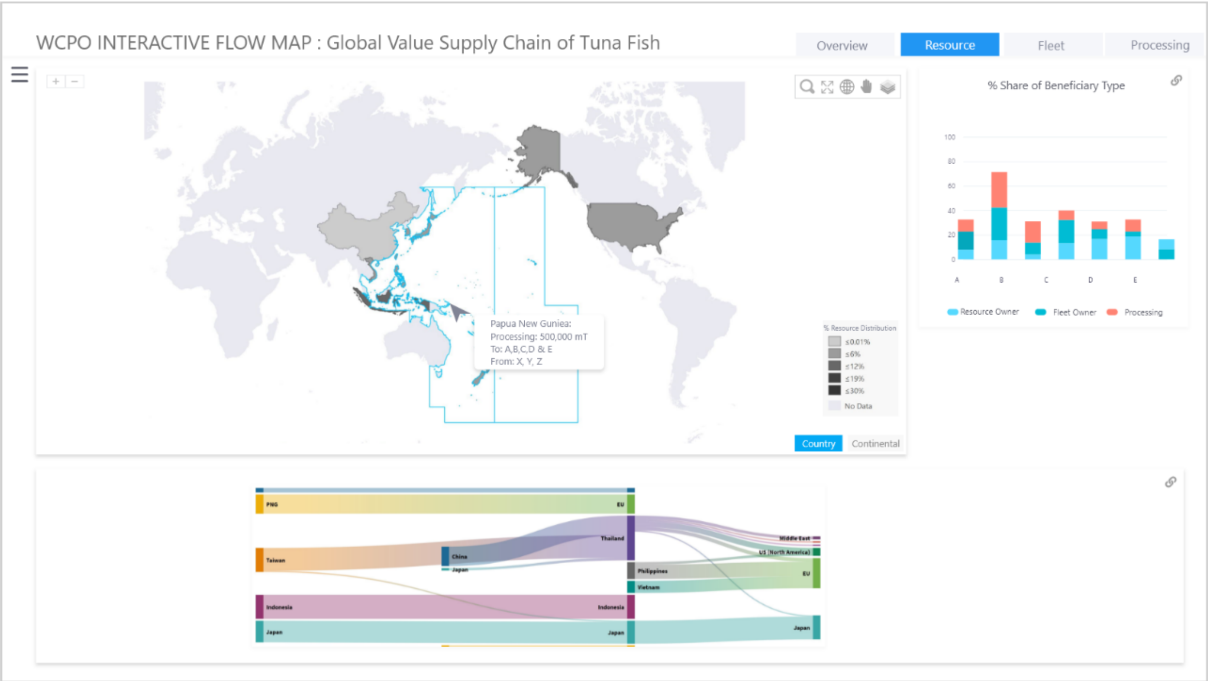


Figure 38: Beneficiary type choropleth distribution maps (clicking on resource distribution)

Tolochko, (2016) describes map composition as the visual hierarchy to emphasize on specific map elements. Muehlenhaus, (2013) suggests categorizing the map composition into 5 visual hierarchy levels. These are adapted for this research and presented in Table 24.

Table 24: Map composition hierarchy adapted for the web from Muehlenhaus, (2013)

Visual Hierarchy Level	Thematic Web Maps
Level 1	Title/splash screen Thematic visualization i.e. flow map Legends
Level 2	Supplementary graphs i.e. Sankey and bar chart Multiple views to show choropleth maps
Level 3	Map interactivity such as linking, filtering, Tooltips Information window or menu such as search, help, about, legend
Level 4	Supplement graphics such as images to explain information within the information windows
Level 5	Metadata, reference information

4.2.3. Interactivity Design

AdobeXD further enables us to provide interaction design where elements of user experience were applied, and interactive design principles and primitives were employed. In User Experience, a high-fidelity interactive mock-up is best to explain the various functions and affordances in the application. For this, AdobeXD provides a prototyping tool to create links between interfaces to offer the ability to click. A short demonstration of the interactive prototype can be seen in the video created here (https://bit.ly/2MtXqBd).

Shneiderman's Visual Information seeking mantra (Shneiderman, 1996) with Bertin, (1983)'s reading levels were used in the creation of the interactions. Other factors such as rules of multiple views by (Baldonado et al., 2000) were also applied. Additionally, the interaction operator primitives described in Table 13 in methods are also used (Tolochko, 2016). These will include zoom, pan, retrieve, filter, search, overlay, linking, and highlighting. The descriptions of these primitives and their purpose are explained in the methods and implemented in the design (section 3.6.3).

Overview:

Considering, Shneiderman's mantra, the first level is an **overview** of the interface as shown in Figure 35. From here one can click on the menu icon to reveal the side pane information. Clicking on each icon in the side pane reveals new panels showing the respective description. **Multiple views:** Switching between distribution map types by clicking on the buttons at the top right changes the map view to display the respective maps e.g. Figure 38 shows the choropleth map view when the resource button has been clicked. Clicking on overview brings the flow map in view. Considering the hierarchical level interaction, the first overview shows data at the country level then clicking on the continent should show at a continental overview (Figure 39).

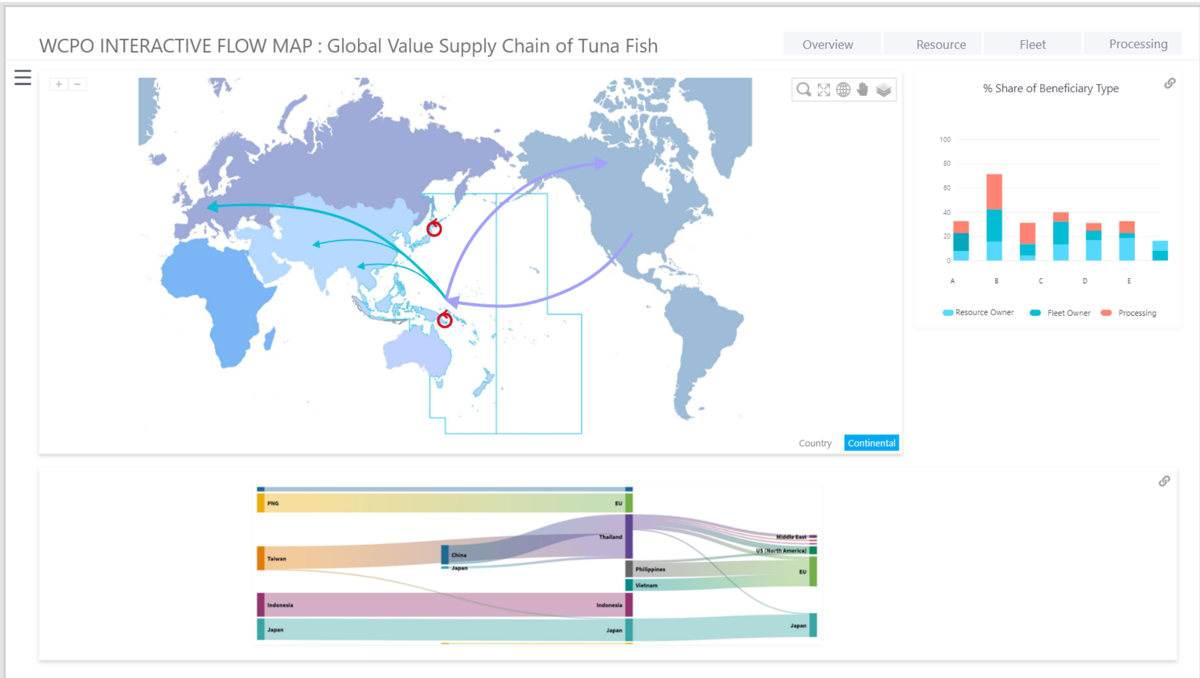


Figure 39: UI/UX design concept at continental aggregation (overview)

Zoom and Filter

Map Interactions such as clicking on zoom buttons allow for map scale to change to view smaller countries. Hovering over the countries also provided filter capability with linked views to the bar chart. Other filter capabilities would include mouse over the flows in the Sankey where the opacity of other flows is reduced to highlight the specifically selected flow of both the Sankey and the map. Highlight and dominance are used to bring the element to the focus of the user. (Figure 40)

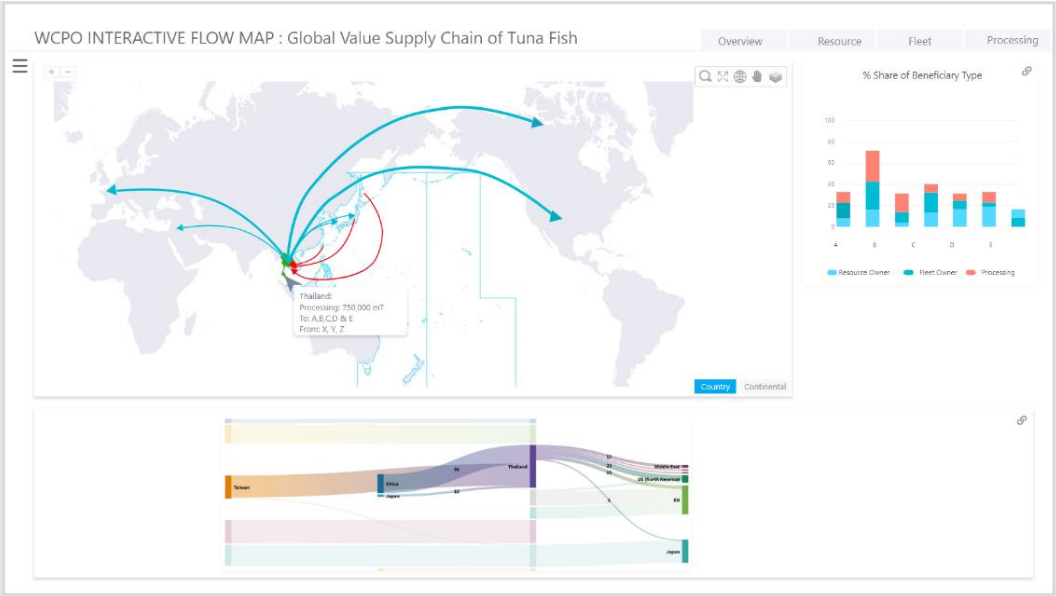


Figure 40: UX design interactivity for clicking on country (zoom and filter of features)

Details-on-demand and Relate

Other interactivity such as hovering aims to provide details on demand by using a tooltip with details for the selected item. In Figure 41, hovering on the flows in Japan provides details in the tooltip and interactively highlights the Sankey and bar chart to show the relationship in flows. Use of the search pane can also provide this where one can simply search the country of interest and visualize all the key details for that country.

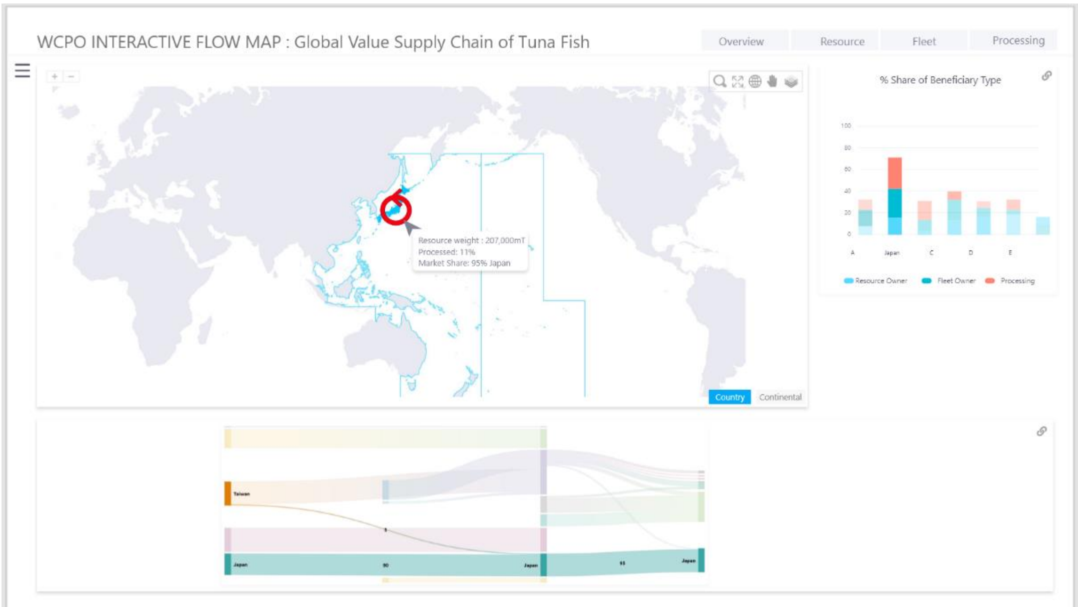


Figure 41: UI/UX design for details-on-demand level by clicking/hover on flow path

4.2.4. Web Map Layout and Composition Design Considerations

There were several design rules considered in the implementation of both the layout and map composition, though not exhaustive, I highlight some of the key principles based on the literature discussed (Table 25).

Table 25: Design Considerations for web layout and web map composition

Design Principles	Description	Implementation
Principles of visual design Lovett, (1999)	Balance	The application was designed with neutral colours to bring balance and put more emphasis on the graphics. Elements are also sized based on importance and striving for balance where graph and Sankey take almost equal weight in size and maps is the largest as it holds more importance in the application.
	Unity	This has been implemented in the data or information panel. According to the Law of Uniform Connectedness, elements that are visually connected are perceived as more related than elements with no connection (Yablonski, n.d.) All the elements presented in the information panel belong together conceptually and logically as they help to provide further knowledge on the application and data hence placed together in one panel. The navigation icons such as zoom in and out are also placed together as they have the same functions which are to provide navigation to the map. Buttons for switching maps are also placed together since they also have similar functions which are to change the map types.
	Hierarchy	Is created through placement, colour, and fonts. Titles were placed at the top and legend at the bottom because top items have higher weight than the bottom and they were made bold and with larger font size than legend. Buttons for switching map views from flow map to choropleth were placed at the top right as this position has a higher weight than the top left. The focal centre or slightly above centre is considered the most important item and other subsidiaries are found to the left and right of this hence map was placed at the focal centre and bar chart and Sankey was found to the right of the map panel.
	Contrast	To make the graphics stand out a neutral grey and white background was used with very vivid colours for the map, bar chart, and Sankey diagram elements.
	Space	White space helps reduce noise hence spaces have been placed in between each visual graphics and along the margins to help reduce noise and compartmentalize items.

	Dominance	This is related to contrast and hierarchy and refers to having an element as a focal point while other elements are subordinate through position, shape size, and colour. Here position and size as explained above are used to depict the maps in the map panel as the focal elements and other graphs such as Sankey and stacked bar chart and supplementary information as subordinate.
Norman's 7 fundamental design rules	Taking advantage of convention	Many web map applications are designed with a dashboard-like appearance with the map being the focal point and having supplementary graphs to aid in understanding the visual. Since this approach has generally be used in many application areas and research work, I take a similar approach to the first design ideas of an interactive web map with a dashboard-like appearance. There are several other general conventions that are employed such as placement in items such as title menu bars based on what is already existing e.g. by convention map titles are place at the top and menu bars appear on the side or maybe hidden as implemented in this design.
	Creating effective visual hierarchies where you are simplifying the structure of tasks to not overload the short-term memory.	As previously stated, visual hierarchy according to (Lovett 1999) is created through placement, colours, and fonts. Here the titles are placed at the top to show importance. The map is at the centre and slightly above centre since it has the most weight in importance as well. The placement of other items such as buttons on the top right corner is chosen as this is also a key place where users will move towards to provide quick access in changing the map types.
	Make things visible	It is important to make obvious or provide affordance e.g. make obvious what is clickable such as where we use buttons or changing the cursor pointer from an arrow to hand when the mouse is over a clickable item as implemented in the interaction design. Fitt's Law also emphasizes the importance of distance in UI design. With this in mind, we place the search panel elements closer to the action list at the second position in the menu items so that the users can easily navigate to it (Yablonski, n.d.).
	Get mapping right	Refers to using graphics and text to make things more understandable. This is provided in the about section where we give descriptions with the images to describe the data mapped.
	Exploiting the power of constraints	To avoid a lot of unnecessary functions, a scenario-based design was chosen to formalize the application requirements and exercise constraint in what is provided.
	Design for error-free	It is important to minimize errors as much as possible. Due to the realization that some countries may be too small to hover or to see in-depth details, a search pane was included as an alternative to find information on a country through search to prevent errors due to scale.

		Errors could also result from aggregation level being viewed in the flow map hence a Sankey diagram that is linked to the flows is included to provide the users with the ability to directly know the name of a location to or from which benefits flow(node names).
Shneiderman's 8 golden rules	Strive for consistency	The application should have a cohesive experience. This was implemented through the use of consistent layout, font, font-sizes, colours, and terminologies.
	Cater to universal usability	The interface should also be adaptable for different types of users such as beginners or experts for this reason. To aid in this, a help menu was added to explain to users how to use the application. A usability testing for this is also carried out after prototype implementation to check if there are key issues that arise for both experts as well as non-experts.
	Offer informative feedback	When an action is complete the system should provide a response. In the implementation when the user clicks on the different map types the choropleth map should be displayed as demonstrated in the interaction design. There are other interactions explained previously that offer informative feedback such as hover of countries, flows, and bars, or click on a map.
	Dialogs yield closure	Action sequence needs to be clear to inform the user the action is complete. In the application, these actions are such as closing and opening of the information panel. This is also implemented in searching where the results are presented after pressing enter or clicking the search in the search panel.
	Prevent errors	This is related to Norma's design rules where users should not commit major errors. Approaches to prevent errors have been explained in "design for error-free" of Norman's design rules.
	Reduce short-term memory load	The interface should not force users to remember large amounts of information e.g. the number of items in any given moment or the categorized elements should not be too many. According to Miller's effect, the average person can only keep 7 (plus or minus 2) items in their working memory (Yablonski, n.d.). Therefore, based on miller's law only 5 of the most important action items are placed in the menu list to reduce performance load. For the same reasons, a maximum of 4 map types (flow map and 3 choropleth maps) are presented and 2 supplementary visuals (bar chart and Sankey).

4.2.5. Visualization and Cartographic Design Considerations

The type of data to be mapped is the weight in metric Tons, dollar values, and %share derived from the weight. The data mainly used in mapping is %share which is quantitative and discrete. This data also has relationships with start and end nodes, and it contains magnitude. Therefore, suitable map types for these purposes are chosen.

A. Flow Map

A flow map has been described as the most frequently used and appropriate form of showing origin-destination data or data with spatial links where the location is of importance. The data to be visualised is unique and contains characteristics where there are intermediary destinations. For this reason, two types of flow maps were initially considered a Sankey flow map versus the generic flow map. A Sankey flow map for branching data would have been a good representation however due to the amount of data being displayed this would have resulted in visual clutter. Another reason why the Sankey flow map was not used is the need to show bi-directionality (represents flows between the same two nodes in opposite direction) which Sankey flows would not easily allow for. Hence the alternative was to use ordinary flow maps for non-branching OD data and use colour to distinguish between locations or steps in the value chain. Here one colour would represent the flow from origin to intermediary destination and another colour would represent the intermediary destination to the last destination i.e. resource to process, fleet to process, and process to market are represented using different colours. OD and flow map principles considered were used to address representation in directionality, magnitude, and bi-directional flows and self-loops.

Directionality can be represented in several ways as discussed by Boyandin, (2013). This research implements directionality using animated flow lines i.e. short segment lines moving in the direction of the flow. This is a recently adopted interactive method that has been proven to be effective as it also eliminates cluttering that may have been caused using arrows as alternatives (Boyandin, 2013).

Magnitude here is represented using size or thickness in flow lines. Size has been noted to be superior as a visual variable for human perception to make a much more accurate comparison (Boyandin, 2013). In this case, magnitude represents the percentage of tuna fish that moves from location X to location P, R, Q e.g. out of the total tuna fish caught by resource owner X, 30% is exported to P for processing 10% is exported to R and 60% is exported to Q.

Bi-directional flows are drawn using Bahoken (2011)'s suggested approach to minimal overlap and clutter technique where the curves are used over straight lines (Boyandin, 2013). Jenny et al.,(2018) states that based on research he found curved flows to perform better than straight lines. The curves should also intersect in such a way that they the offer largest possible acute angles to avoid overlaps.

Self-loops, in this case, occurs when the origin and destination are the same locations e.g. Japan processes tuna fish and consumes 95% of it domestically hence the flow of the process to market is a self-loop or closed loop. This has been presented in the design using a circle with an arrow, however, due to clutter with the arrow, we opted to change the design to be an ellipse as will be seen in the implementation of the prototype.

B. Choropleth

The data that is used to show the percentage distribution of fleet, processing, and resource is relative discrete data and therefore the most suitable map type for this type of data is a choropleth map (Alkema et al., 2013). This data is ordered to show a comparison between countries in the distribution of resource, fleet, or processing. Based on the principles in visual variables(Roth, 2017), a good representation of this would be colour value. The data was initially classified into 8 classes and a sequential colour scale was chosen to represent data with varying shades of blue. However, after usability testing due to a lack of cognitive ability to distinguish that many colours, this was reduced to 6 classes. Choropleths are hence chosen as supplementary graphics to aid in understanding of the distribution of magnitude per beneficiary type.

C. Sankey

A Sankey diagram is used to visualize spatial interactions or OD data where a spatial location is not explicit, and it serves two purposes. One is that it allows users to visualize information regardless of the spatial resolution e.g. names of locations can be at country or continental levels. The other is that when interactively linked to a flow map one can determine the names of the locations where countries may be too small to distinguish. A Sankey is hence chosen as a supplementary graphic to aid in the understanding of the spatial interactions or flows from and to a location.

D. Bar chart

The bar chart chosen is a stacked bar chart which is mainly for comparison purposes of the weight in a metric ton of tuna fish caught as resource owner, fleet owners, or processed by country. The magnitude visualized on the y-axis is the percentage of the weight in metric tons of tuna fish over the total WCPO fisheries for that segment e.g. China has 4% of the total number of fleets fishing in the region or Indonesia catches 11.7% of the total fish caught as a resource owner in the region. The bar chart is the most suitable choice for visualizing amounts and comparison compared to the pie chart visualizations presented in the (World Bank and Nicholas Institute, 2016) report since human perception allows us to make the comparison more easily with rectangles over other shapes such as pie chart (Wilke, n.d.).

Colour choice and Typography

Suitable colours and choice of fonts, font-size, and placement is a key role in user interface design. It should be designed to provide a cohesive appearance. Placement of information such as map titles, legend, axis labels should not clutter the layout and should provide the perception of hierarchy of the most important items e.g. map titles are placed at the top as they are more important than other text. Colours chosen for the text are a subtle grey colour to reduce dominance as the focus is on the graphic elements.

The number of colours chosen in the web map should ideally not be more than 8 for each visualization to prevent memory overload. For this reason, only 3 main colours are chosen for the flows and the bar chart. Rühringer, (2018)'s provides map recommendations and mentions that it is vital to choose colours suitable for visual disability such as colour blindness. Red and blue combination and red and purple combinations have been presented as combinations that are easily distinguishable for different variations of colour blindness hence the main colours used in this flow map and bar chart are red, blue, and purple (Rühringer, 2018; Brewer, 2016, p.169).

The Sankey diagram colours were initially based on the default colour choices of d3.js' schemeCategory10. However, this resulted in poor colour combinations as was pointed out in the usability testing section 4.4.3 by TP5. For this reason, the colour red was eliminated from this category to address red-green colour blindness. Colours chosen for the Sankey are nominal and hence varying shades are repeated due to the number of colours available to work with. This does not have any significant meaning when countries may have similar or varying shades of the same colours.

In conclusion, this section presents the results of the conceptual designs in the form of low and high-fidelity visual mock-ups which was accessible for review using AdobeXD. The outcomes of the conceptual design allow the developer to translate these and create a functional and relational framework that can be used in implementing a working prototype for the next phase of this research.

4.3. Prototype Implementation (Produce Design Solution)

The prototype implementation phase entails translating the design concepts into a working prototype using several technologies. In this section I discuss the process of creating a web application which starts with data acquisition and preparation, pre-processing, database design and storage, and front-end interface implementation. In doing this I address the third objective of the research *"To build and implement an interactive web mapping prototype to facilitate visualization of marine ES flows".* The method used here is based on the prototypical framework that was adapted from Donohue,(2014) in Figure 28 (section 3.7.1)

4.3.1. Data Acquisition and Data Pre-processing

In the methodology section 3.5.1, I discussed the available data that was acquired for this research and its sources. I also described the general features of the data, attributes, and units and the criteria for deciding what data to consider for purposes of prototype demonstration. I concluded that the data has some unique attributes or specificities which allowed us to make key decisions in the design concepts such as choosing to represent it using a flow map and Sankey diagram. The next step here is to further describe the specific data that was acquired based on the decision criteria and explain how it was pre-processed.

Selection Data based on Decision Criteria

Global tuna fisheries form complex, supply value chains across the world, and the best available information for each are summarized along with the following general segments of the supply chain: resource owners, harvesting units/fleet owners, processing segment (canning and loining; including distribution) or retailing segment. Based on the decision criteria chosen in the methodology the data that was acquired and filtered based on logical consistency and homogeneity, spatial and temporal completeness, attribute accuracy, resolution accuracy, and usage purpose. Therefore, the resulting data that is selected has the following characteristics:

- Data of all tuna fish species were considered due to data completeness and availability.
- Data for the year 2013 was used. Completeness of the data was only available in all segments for this period or a time indicative of this period.
- Data based on the purse seine fisheries or fishing gear type is used since this is also the most complete data for all segments in the value supply chain discussed in the Pacific Possible project report.
- Segments that were mapped in the supply value chain include resource owners, harvesting units/ fleet owners, and processing segments. The retailing or marketing segment did not have data that is specific to the WCPO region hence was not explicitly mapped for its distribution.

The flow map and Sankey diagrams show the movement of tuna fish from the supply (resource owners or fleet owners) to the processing locations and then to the market locations where the processed tuna is exported to. The choropleth maps and bar chart mapped the share in percentage distribution of resource, fleet, and processing segments. These datasets were acquired filtered in Excel and pre-processed. In this research, segments and beneficiary type has been used interchangeably e.g. a country that is in resource owner segment is resource beneficiary type, processing segment is processing beneficiary type. The type of data described is characteristic of OD data. The nodes or locations in the spatial interactions are the locations of the beneficiaries. The magnitude mapped is the %share distribution by beneficiary type and the direction of the flows refers to the direction with which tuna fish moves in the global supply value chain. A country that is a resource owner may sometimes also be a fleet owner hence to map the flows we consider 3 steps or types of flows:

- From locations that are fleet or resource owners to processing locations
- From locations that are fleet owners only to processing locations
- From processing location to market destination

Data Acquisition

The data was derived from reports and downloaded Excel sheets. It was then compiled in Excel as shown in Figure 42. Two different data sources were mainly documented and used (FFA, 2016; World Bank and Nicholas Institute, 2016). However, due to completeness of the data for all segments, the data from World Bank and Nicholas Institute, (2016) was preferred and the FFA data was only considered when there was missing information in the first dataset. It is important to note that the data presented in FFA however differs by a margin of 2% to that provided by the WCPFC and from figures shown in the World Bank and Nicholas Institute, (2016) report. The indicator data as described in the methodology for each segment and their related position in the OD data structure are:

- Resource Owner – Catch by national waters (MT, %) as an origin location.
- Fleet Owner – Catch by Fleet (MT, %) as an origin location
- Processing Segment - Processing weight of tuna (MT, %) as an intermediary destination.
- Market segment – derived from exports in the processing segment as percentage distribution and are the final destinations.

Resource Owner (Catch/Supply): Refers to the fish caught by countries that own the resource or rights for fishing within the area. The data provided is in metric tons from both the data sources. The data is also available in US dollar value in the FFA report however %share is what is used in the mapping. The World Bank and Nicholas Institute, (2016) focuses on the years 2013 and 2014 due to completeness for these years in other segments, and hence for this research, we only use 2013.

Catch by national waters by gear by species
All values in metric tonnes

	Data source: FFA Data Sheet			Data source: World Bank and Nicholas Institute Sheet	
	2013			2013	
	Catch (mT)	% of Total		Catch (mT)	% of Total
3.1 Purse seine by Catch (mT)			**3.3 Purse seine by Catch (mT) by World Bank**		
PNA Members			**PNA Members**		
FSM	209,345	11.40	FSM	210,453	11.39
Kiribati	283,861	15.46	Kiribati	282,466	15.29
Nauru	163,404	8.90	Nauru	161,795	8.76
Palau	310	0.02	Palau	310	0.02
PNG	585,877	31.90	PNG	591,252	32.00
Marshall Islands	39,655	2.16	Marshall Islands	39,635	2.15
Solomon Islands	111,456	6.07	Solomon Islands	107,629	5.83
Tokelau	15,746	0.86	Tokelau	15,856	0.86
Tuvalu	54,155	2.95	Tuvalu	52,892	2.86
Sub-Total PNA + Tokelau	**1,463,809**		**Sub-Total PNA + Tokelau**	**1,462,288**	
Others		0.00	**Others**		
American Samoa	493	0.03	American Samoa	497	0.03
Cook Islands	8,335	0.45	Cook Islands	8,338	0.45
Indonesia	215,646	11.74	Indonesia	215,651	11.67
Japan	14,441	0.79	Japan	14,441	0.78
Korea	234	0.01	Korea	234	0.01
New Zealand	12,635	0.69	New Zealand	12,754	0.69
Philippines	89,432	4.87	Philippines	101,711	5.51
Samoa	31	0.00	Samoa	32	0.00
Taiwan	4,510	0.25	Taiwan	4,510	0.24
China	0	0.00	China	0	0.00
US	4,498	0.24	US	4,501	0.24
Vietnam	22,484	1.22	Vietnam	22,484	1.22
Wallis & Futuna	0	0.00	Wallis & Futuna	0	0.00
Sub-Total Other National Waters	**372,740**		**Sub-Total Other National Waters**	**385,153**	
International waters	98,898		International waters	69,831	
TOTAL	1,836,548	100.00	**TOTAL**	1,847,441	100

Figure 42: Example of Initial Data Acquisition of catch by national waters from FFA and World Bank and Nicholas Institute

Major players in this segment are Kiribati and Papua New Guinea who in 2014 estimated to catch almost 50% of total fish caught by the region. Other major resource owners like Indonesia and the Philippines caught 16% in national waters. The spatial resolution of this data is at the country level. Figure 42 shows is a sample sheet of some of the extracted data from the reports with a preliminary calculation on percentages.

Harvesting / Fleet Owner: These are the fleet vessel owners that harvest within the WCPO waters including tuna trading companies working with harvesters. The data available here are provided by both sources in metric tons as well as in US dollar value. This is also available for the years 2014 and 2013, however, the World Bank and Nicholas Institute, (2016) report provides more in-depth information such as destination for processing, number of vessels among other details for the year 2013. The spatial resolution of this data is at the country level. Mobile fleets follow tuna stock as they move across national boundaries. Approximately 47% of the catch in 2013 was by four main distant water fleets from Taiwan, China, Japan, Korea, and the United States, 23% was by Pacific Island fleets and 20% largely by domestic fleets in Indonesia and Philippines. In 2013, 77% of WCPO purse seine was taken by foreign fleets to Pacific Island. A sample of the extracted data is shown in Figure 43.

Catch by Fleet of WCPO purse seine fleet segments
All values in metric tonnes

Data source: FFA Data Sheet		**Data source: World Bank and Nicholas Institute**							
	2013	**2013-2014**							
	Catch (mT)	Fleet Owner (Harvest)	catch(mT)	Vessels operating	% of total catch	Fishing Waters	Transhipping Port	Transhipped to (for Processing)	%
4.1 Purse seine catch by fleet (mT)		**4.2 Purse seine value by fleet ($)**							
PNA Members		**Largest Distant-water fleets(47%)**							
FSM	24,182	Japan	206999	40	11%	PNG	Japan	Japan	90%
Kiribati	72,241					Solomon Island		Thailand	10%
						FSM			
						WCPO			
PNG	192,967								
Marshall Islands	75,641	Taiwan, China	212480	34	11%	WCPO	Pacific Island	Bangkok	95%
Solomon Islands	24,769							Japan	5%
Tuvalu	11,416								
Vanuatu	20,099	Korea	225632	28	12%	PNA	Pacific Island (Pohn	Korea	
						High seas		Bangkok	
Others									
American Samoa	172								
		United States	254342	40	13%		Pacific Island (Pohn	Bangkok	
Ecuador	21,442							Latin America	
El Salvador	13,273								
Indonesia	215,581								
Japan	207,012								
Korea	225,461	**Pacific Island fleets (23%)**							
New Zealand	24,430								
Philippines	186,449	PNG	192967	51	12.5	Pacific Island cou	PNG	PNG Canneries	20%
Spain	45,010							EU	80%
Taiwan	216,990								
China	81,828								
US	254,161	Solomon Islands	24769	5	1.2				
Vietnam	22,484								

Figure 43: Example of Initial Data Acquisition Catch by Fleet of WCPO purse seine fleet segment from FFA and World Bank

Processing Segment (canning and loining): Tuna fish caught is exported to locations where it is processed through canning and loining. This canned fish is then exported to several markets for consumption. The markets may be as far as European and North American due to an increasingly globalized supply chain (Hamilton et al., 2011). In 2010 the major tuna canner was Thailand with the main canning taking place in Bangkok and this is followed by Japan, Ecuador, and the Philippines. Due to the change in market conditions, fishing areas, and processing facility requirements, the balance between different channels for processing may be constantly shifting. Despite this, the breakdown from the WCPO's tuna catch in 2010 is indicative and can be assumed for later years. Since the data for 2013 was not available, the information derived here varies from 2009 to 2010 and is assumed to be suggestive of what the situation would have been in 2013. The data is derived from World Bank and Nicholas Institute, (2016) in metric tons and percentage of processing. The final markets as to where the tuna is exported are also provided for some of the countries in the percentage share exported based on the total export of that country. The spatial resolution of these datasets varies between country-level and trans-national or continental levels (Figure 44).

Processing of WCPO Purse Seine Catch in 2010
All values in metric tonnes

Data source: World Bank and Nicholas Institute
2009 - 2013

5.1 Processing Countries

Largest Processing Countries	Metric (mT)	% of Processi	Final Markets	% Market
Thailand	750000	12	US (North Am	23%
			EU	15%
			Middle East	12%
			Australia	6%
			Canada	6%
			Japan	5%
Japan		11	Japan	95%
Philippines	220000	9	EU	60%
			US (North Am	10%
Korea	130000	8	Korea	100%
PNG	100000	8		
Solomon Island	15200	5		
Fiji		5		
Kiribati		1		
Marshal Islands	10000	5		
Ecuador	70000	7	EU	70%
			US	20%
			Latin America	10%
Vietnam	35000	6	US	50%
			EU	50%
Indonesia		6	EU	30%

Figure 44: Example of initial acquisition of processing segment from World Bank and Nicholas Institute, (2016)

Data Pre-processing

The datasets acquired were then calculated for all percentage shares to have a standard unit for the purpose of integrating all datasets in the flow map and choropleth maps. The data was first re-organised for the purpose of viewing the baseline overview of distribution. The attributes derived from the data pre-processing are shown in Table 26.

Table 26: Indicators of mapping MES flows of tuna fish and their attributes

Dataset	Field Attributes
Resource Owner	Country name Catch (MT) Percentage catch (%) Value ($) Percentage value (%)
Fleet Owner	Country name Catch (MT) Operating vessels Percentage catch (%) Transhipped To
Processing & Market	Country name Catch (MT) Percentage processing (%) Final markets (%)

	A	B	C	D	E
1	Country	Catch(mT)	Operating Vessels	Perc_Catch	Transhipped To
2	Japan	206999	40	11	[{name: "Japan", perc_share:90}, {name:"Thailand", perc_share:10}]
3	Taiwan	212480	34	11	[{name: "Bangkok", perc_share:95}, {name:"Japan", perc_share:5}]
4	Korea	225632	28	12	[{name: "Korea", perc_share:}, {name:"Bangkok", perc_share:}]
5	United States	254342	40	13	[{name: "Bangkok", perc_share:}, {name:"Latin America", perc_share:}]
6	PNG	192967	51	12	[{name: "EU", perc_share:80}, {name:"PNG Canneries", perc_share:20}]
7	Solomon Islan	24769	5	1	
8	FSM	24193	10	2	
9	RMI	77634	10	2	[{name: "Bangkok", perc_share:}, {name:"Majuro", perc_share:}]
10	Kiribati	72241	14	3	[{name: "Bangkok", perc_share:100}]
11	Vanuatu	22484	3	1	[{name: "Bangkok", perc_share:100}]
12	Tuvalu	10866	1	0	
13	Indonesia	215582		12	[{name: "Indonesia", perc_share:}, {name:"Bangkok", perc_share:19}]
14	Philippines	148552	40	0	[{name: "Bangkok", perc_share:15}, {name:"PNG", perc_share:},{name:"Philippines", perc_share:}]
	China				[{name: "Bangkok", perc_share:81}, {name:"China",

Resource Owners | Fleet Owners | Processing&Market | Retailers

Figure 45: An example of the integrated country distribution of tuna fish caught by fleet owners

Figure 45 shows the relationships in the data sets for fleet owners e.g. Taiwan exports tuna to Japan for pre-processing. From these relationships and those in other segments, I manually derive the spatial interactions to create an OD structured data set (Figure 46). I also include country and continent codes to attribute spatial data to these data sets and indicate the origin and destination locations using the country codes as well. The steps to and from and "O" and "D" show the movement of flows i.e. if it is from 'fleet/resource owner to processing' or 'fleet owner only to processing' or 'processing to market'.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Origin	orig_countCode	countrycode	orig_contcode	Destination	countrydestcode	dest_countCode	dest_contCode	Value_share	StepFrom	StepTo	O	D
2	Korea	KOR55	18	CU03	Korea	18	KOR55	CU03	100	2	3	p	m
3	Thailand	THA42	23	CU03	Australia		AUS225	CU06	6	2	3	p	m
4	Thailand	THA42	23	CU03	Canada		CAN202	CU05	6	2	3	p	m
5	China	CHN195	2	CU03	China	2	CHN195	CU03	19	1	2	f	p
6	Ecuador	ECU177	4	CU08	EU	21		CU04	70	2	3	p	m
7	Indonesia	IDN143	8	CU03	EU	21		CU04	30	2	3	p	m
8	Philippines	PHL80	17	CU03	EU	21		CU04	60	2	3	p	m
9	Thailand	THA42	23	CU03	EU	21		CU04	15	2	3	p	m
10	Vietnam	VNM3	28	CU03	EU	21		CU04	50	2	3	p	m
11	PNG	PNG83	16	CU06	EU	21	ESP54	CU04	80	0	2	fr	p
12	Indonesia	IDN143	8	CU03	Indonesia	8	IDN143	CU03	81	0	2	fr	p
13	Japan	JPN135	9	CU03	Japan	9	JPN135	CU03	95	2	3	p	m
14	Thailand	THA42	23	CU03	Japan	9	JPN135	CU03	5	2	3	p	m
15	Japan	JPN135	9	CU03	Japan	9	JPN135	CU03	90	0	2	fr	p
16	Taiwan	TWN45	22	CU03	Japan	9	JPN135	CU03	5	0	2	fr	p
17	Korea	KOR55	18	CU03	Korea	18	KOR55	CU03	0	0	2	fr	p
18	Ecuador	ECU177	4	CU08	Latin America	26		CU08	10	2	3	p	m
19	United Stat	USA16	26	CU05	Latin America	26	USA16	CU08	0	0	2	fr	p
20	Indonesia	IDN143	8	CU03	Middle East			CU03	30	2	3	p	m
21	Thailand	THA42	23	CU03	Middle East			CU03	12	2	3	p	m
22	Philippines	PHL80	17	CU03	Philippines	17	PHL80	CU03	0	0	2	fr	p
23	Philippines	PHL80	17	CU03	PNG	16	PNG83	CU06	0	0	2	fr	p
24	PNG	PNG83	16	CU06	PNG	16	PNG83	CU06	20	0	2	fr	p
25	RMI	PNG83	12	CU06	RMI	12	MHL10	CU06	0	0	2	fr	p

Figure 46: Pre-processed origin destination structure

The final step before database ingestion was compiling all the segments into one data sheet based on the country and creating a country distribution dataset where the attributes of each country are populated with the relevant data information. These were attributed to country codes and continent codes to enable us to create joins with spatial datasets such as country or continent shapefiles. The attributes hence in this pre-processing stage include County name, Country code, Continent Code, percentage resource, resource catch (MT), resource value ($), percentage fleet, fleet catch, fleet vessel, percentage processing, and processed weight (see Figure 47).

	A	B	C	D	E	F	G	H	I	J	K
1	Country	Country_code	Continent_code	PercResource	resourceCatch_metricTons	resourceDollar_value	PercFleet	fleetCatch_mT	fleetVessel	PercProcessing	processingCatch_mT
2	American Samoa	ASM14	CU06	0.03	497	1043836		0		0	
3	China	CHN195	CU03	0	0	0	4	81871	69	0	
4	Cook Islands	COK95	CU06	0.45	8338	17491497		0		0	
5	Ecuador	ECU177	CU08	0			1	21453		7	70000
6	El Salvador	SLV175	CU05	0			1	13276		0	
7	Fiji	FJI170	CU06	0				0		5	
8	Federated States of Micronesia	FSM9	CU06	11.39	210453	421607056	2	24193	10	0	
9	Indonesia	IDN143	CU03	11.67	215651	456983200	12	215582		6	
10	Japan	JPN135	CU03	0.78	14441	27725365	11	206999	40	11	
11	Kiribati	KIR131	CU06	15.29	282466	597230501	3	72241	14	1	
12	Republic of Korea	KOR55	CU03	0.01	234	401079	12	225632	28	8	130000
13	Marshall Islands	MHL10	CU06	2.15	39635	83413466		0		5	10000
14	Nauru	NRU100	CU06	8.76	161795	343651985		0		0	
15	New Zealand	NZL93	CU06	0.69	12754	26153790	1	24430		0	
16	Palau	PLW85	CU06	0.02	310	540519		0		0	
17	Philippines	PHL80	CU03	5.51	101711	188867553	0	148552	40	9	220000
18	Papua New Guinea	PNG83	CU06	32	591252	1226534211	12	192967	51	8	100000
19	Marshall Islands	MHL10	CU06	0			2	77634	10	0	
20	Samoa	WSM70	CU06	0	32	66335		0		0	
21	Solomon Islands	SLB59	CU06	5.83	107629	234630526	1	24769	5	5	15200
22	Spain	ESP54	CU04	0			2	45010	4	0	
23	Taiwan	TWN45	CU03	0.24	4510	9335700	11	212480	34	0	
24	Thailand	THA42	CU03	0				0		12	750000
25	Tokelau	TOK241	CU06	0.86	15856	32988903		0		0	
26	Tuvalu	TUV242	CU06	2.86	52892	113455121	0	10866	1	0	
27	United States	USA16	CU05	0.24	4501	9513281	13	254342	40	0	

Figure 47: Example of Fleet Owner sheet of the pre-processed data

4.3.2. Database Design Curation and Storage

From the output CSV files of the pre-processed OD data and the integrated country file, I used python scripting to push this data to a PostgreSQL database and PgAdmin to manage the data in the tables. Python scripting was used to connect to the created database, design and create tables in the database, clean up the files and insert the records into the tables in the database (the code scripts are provided in the metafiles of the research). To store the spatial files in the database, the ogr2ogr command line tool was used to store shapefiles in the PostgreSQL tables. The spatial files included country and continent shapefile. Using SQL Queries, I joined the spatial data with the CSV and create centroids for the flow map origin and destination locations based on the country codes. For the cases where country-level data was missing e.g. market destinations in the EU the centroid of the continental level is used. However, based on usability testing as advised from expert users, this was later shifted to the capital of the European Commission i.e. Brussels due to ambiguity in the information presented.

The next step was the creation of the final output files using python that would be used in the front-end implementation. This entailed connecting to the database, querying the database, and restructuring the data to the required structure for use in the front-end and writing the output to data files in the correct format. To achieve proper representation and manipulation of the data in the solution space using D3.js, the structure of the data had to be in a specific format namely JSON for the flow map structure, Sankey diagram structure and stacked bar chart structure as in Figure 48 and CSV for the search pane bar graph as shown in Figure 49.

```
[
    {
        "id": 7,
        "continent": {
            "id": 7,
            "fromName": "Asia",
            "origin": [
                84.5681,
                32.2433
            ],
            "toName": "Asia",
            "destination": [
                84.5681,
                32.2433
            ],
            "beneficiary_typefrom": "p",
            "beneficiary_typeto": "m"
        },
        "country": {
            "id": 7,
            "fromName": "South Korea",
            "origin": [
                127.839,
                36.3852
            ],
            "toName": "South Korea",
            "destination": [
                127.839,
                36.3852
            ],
            "beneficiary_typefrom": "p",
            "beneficiary_typeto": "m"
        },
        "value": 100
    },
    {
```

```
{
  "nodes": [
    {
      "name": "Latin America",
      "category": "CU08"
    },
    {…},
    {…},
    {…},
    {…},
    {…},
    {…},
    {…},
    {…},
    {…},
    {…},
    {…},
    {…},
    {…},
    {…},
    {…},
    {…},
    {…},
    {…},
    {…}
  ],
  "links": [
    {
      "source": "Ecuador",
      "target": "Latin America",
      "value": 10,
      "category": "p-m",
      "source_contcode": "CU08",
      "dest_contcode": "CU08",
      "codeId": 2
    },
    {
      "source": "Ecuador",
```

```
{
  "continent": [
    {
      "code": "CU01",
      "Resource Owner": 3.8,
      "Fleet Owner": 8,
      "Processing": 0,
      "name": ""
    },
    {…},
    {…},
    {…},
    {…},
    {…}
  ],
  "country": [
    {…},
    {…},
    {
      "code": "CK",
      "Resource Owner": 0.5,
      "Fleet Owner": 0,
      "Processing": 0,
      "name": "Cook Islands"
    },
    {
      "code": "EC",
      "Resource Owner": 0,
      "Fleet Owner": 1,
      "Processing": 7,
      "name": "Ecuador"
    },
    {
      "code": "SV",
      "Resource Owner": 0,
      "Fleet Owner": 1,
      "Processing": 3,
      "name": "El Salvador"
    },
```


Figure 48: Final data structure in json format; from left: Flow map structure (flows.json), Sankey diagram structure (sankey_data.json) and Stacked bar chart (stackedDataPrepared.json)

fid	country_name	country_code	id	continent_code	perc_resource	resource_catch	resource_value	perc_fleet	fleet_catch	fleet_vessels	perc_processing
16	Samoa	ASM14	AS	CU06	0.03	497	1043836	0	0	0	0
156	China	CHN195	CN	CU03	0	0	0	4	81871	69	0
184	Cook Islands	COK95	CK	CU06	0.45	8338	17491497	0	0	0	0
218	Ecuador	ECU177	EC	CU08	0	0	0	1	21453	0	7
222	El Salvador	SLV175	SV	CU05	0	0	0	1	13276	0	0
583	Micronesia	FSM9	FM	CU06	11.39	210453	421607056	2	24193	10	0
242	Fiji	FJI170	FJ	CU06	0	0	0	0	0	0	5
360	Indonesia	IDN143	ID	CU03	11.67	215651	456983200	12	215582	0	6
392	Japan	JPN135	JP	CU03	0.78	14441	27725365	11	206999	40	11
296	Kiribati	KIR131	KI	CU06	15.29	282466	597230501	3	72241	14	1

Figure 49: Final csv data format for search panel bar graph (beneficiary.csv)

The format of output files needed for the front-end is GeoJSON, TopoJSON, and CSV. In some cases, mapshaper.org, an online conversion tool for spatial data, was utilized to convert GeoJSON files and the WCPO boundary shapefile to TopoJSON format. TopoJSON is a preferred file format because it is of a smaller size as it eliminates redundancy by encoding coordinates with a more efficient fixed-precision integer. The advantage with smaller file sizes is that it enables the application to load faster and provides smooth interactivity.

4.3.3. Solution Space

As presented in the literature review and the methodology, technologies including HTML, CSS, JavaScript, and JS libraries such as Bootstrap and Popper and other additional accessories such as font-awesome are required for front-end implementation. The main JS library used to interact with the data, manipulate it, and offer visual graphics is D3.js. It is a JavaScript library that allows for the manipulation of Scalable Vector Graphics (SVG). It is quite flexible and scalable and is considered a very powerful library for data visualization in general and it is supported by every modern browser (Bostock et al., 2011; Maleki, 2016).

Developing an application using D3 requires that all the data files and resources be accessed from the same server URL. For this reason, a server provided by ITC Faculty, University of Twente was used for the development stage. Hosting in a server as opposed to file-based development allows us to reference the data in the same domain and hence avoid cross-domain errors. To create the front end a functional or relational framework of the working of the application is derived from the design concepts produces in section 4.2. The functional design of the interactive web application describes the various components, pages, and interactions to be considered in the final prototype implementation as shown in Figure 50.

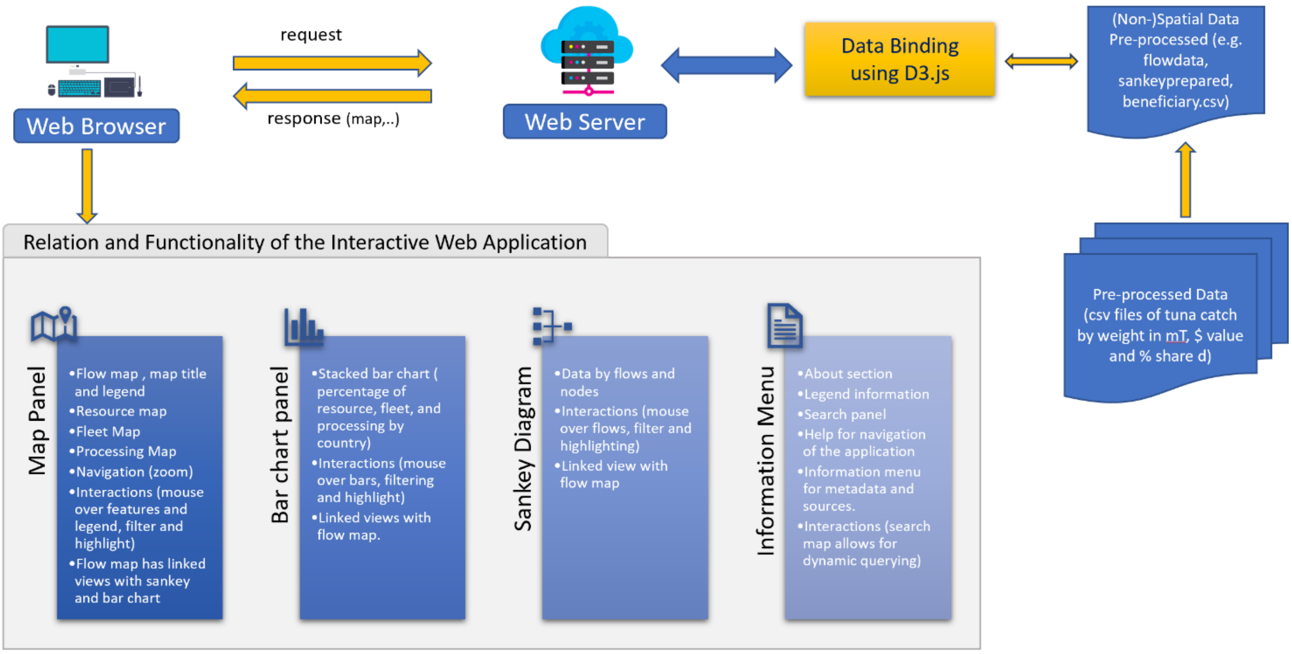


Figure 50: Functional requirement of the web application as derived from the conceptual designs

Web Architecture

The application was created, and its functional working based on the front-end web architecture presented in Figure 51. Users interact with the application on the client-facing side using a web-client such as a browser. The user is first presented with an overview page and can interact with the application to perform filtering, switch between views, highlight, and other interactions.

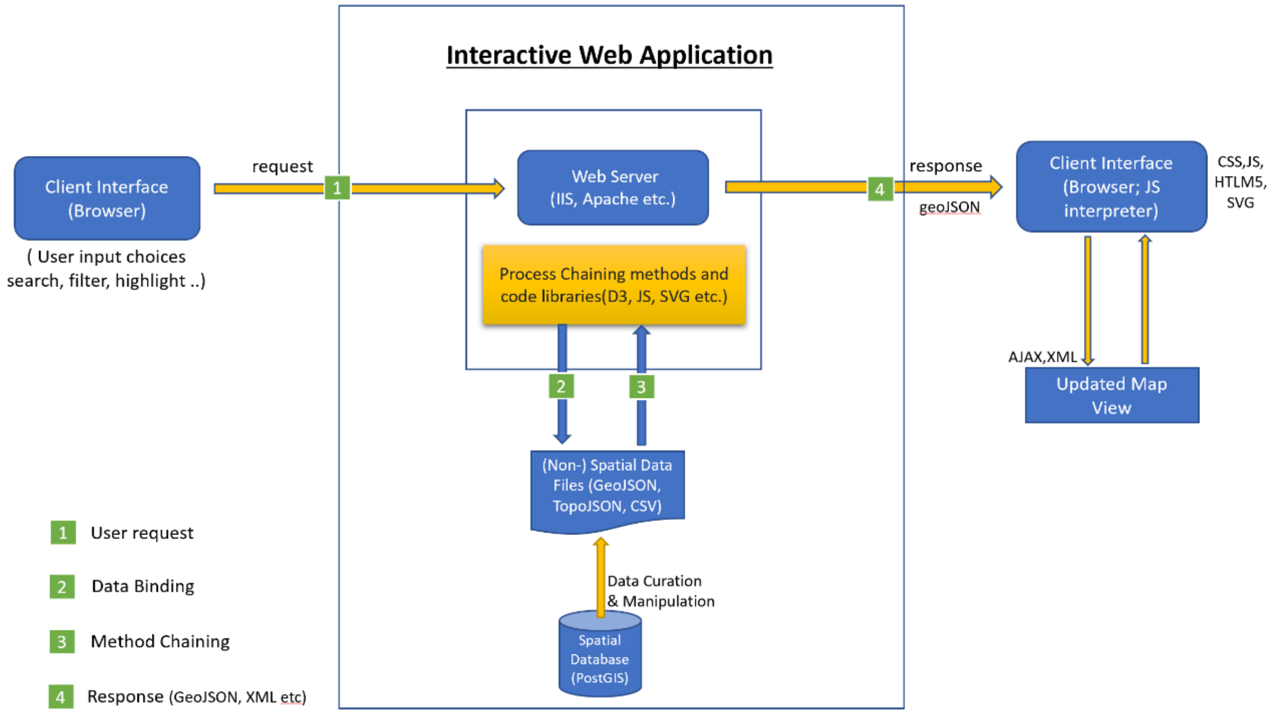


Figure 51: Interactive Web Application Architecture

When the user performs an action e.g. search, this is known as a request from the client which is sent to a web server that processes the request by reading the data files, and depending on the type of request it sends back a response with a payload (data). The response then results in changing the view of the visualization dynamically to display the requested view. This general update pattern describing the request, response, and update to the browser are made possible by D3.js. D3 is built on a series of injectors which allows for dynamic view and manipulation of Document Object Model (DOM) elements using process chaining (Figure 52). The four main components of the process chaining (Dunnewind, Gupta, van Schooten, & van der Veeken, 2016):

- **Input data** is a collection of entries containing the information to be visualized.
- **Element binding** refers to the relation between data entry and an element in the DOM.
- **Method chain** is the chain of methods that define element parameters based on the data.
- **DOM** (Document Object Model) is the document elements in the web page that the entries are bound to through the element-binding (Dunnewind et al., 2016).

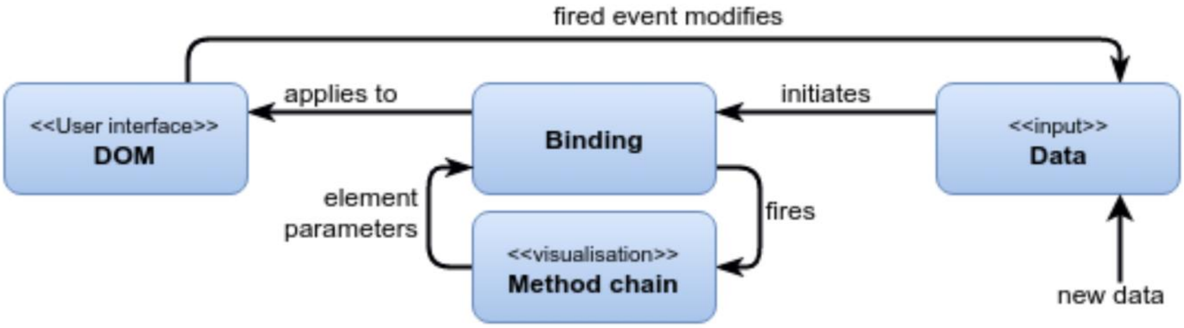


Figure 52: D3.js' process chaining method for data-driven documents (Dunnewind et al., 2016)

Front-end Application

The application was created employing the technologies mentioned, the design concepts, and the relational framework. Contrary to the UI layout of the components presented in the conceptual design, we shifted the Sankey panel component to the right to allow for the map to have a larger space as it is the most important item. Figure 53 shows the overview of the application which includes the flow map, Sankey diagram, and stacked bar chart at the country level. All the data used was read from specific files for each visualization. The flow map used the flows.json file, the Sankey used sankey_data.json, the choropleth map used the beneficiary.csv file, the bar chart used the stackDataPrepared.json file and for boundaries, worldcountries.json and wcpo.json files were used.

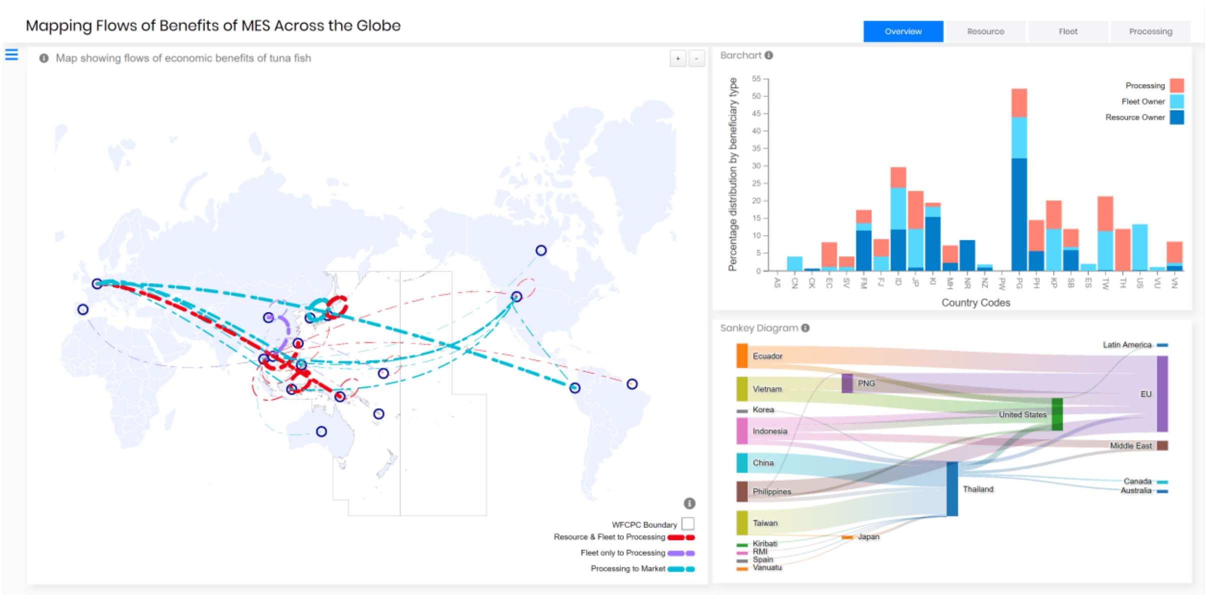


Figure 53: Prototype Implementation Overview of the User Interface

Continental level visualization was not implemented since the flow lines would aggregate to five origins and destinations and the meaning of the relationships would be lost. Hence country level was maintained with the addition of a Sankey diagram that is interactively linked to determine the actual origin and destinations regardless of the resolution mapped. The flow map shows the flow segments which are distinguished using colour for *origins* (either resource or fleet owners, fleet owners only or processing) to *destinations* (processing locations or market location). The WCPO boundary is also included to delineate the region for which the fishing is carried out, however, it is indicated with subtle colour to reduce dominance.

The **flow map** describes the MES flows in the supply chain from resource or fleet to processing and market. Interactivity functions implemented in the flow map include zooming in and out and hovering over the legend which filters the flows displayed by highlighting them. Hovering over the countries displays the country names and over the flow path displays the details of the path e.g. Ecuador exports 70% share to EU as processing to market. Information icons are also used to describe the visualization panel. The flow maps were implemented using animated flow segments to depict the movement of the flows. The code used in the implementation of these flow lines was a refactored work derived from Boyandin, (2013) and Maleki, (2016).

The **stacked bar chart** presented shows the percentage distribution of each segment by country i.e. %processed tuna, % tuna catch for fleet owners, or resource owners by a country. It is mainly used for making comparisons by countries that participate in the tuna fishing industry by beneficiary type. It is interactively linked with the flow map such that hovering over a country highlights the bar or vice versa. Other interactivity actions include details on demand where a tooltip displays the breakdown details of %share distribution for each country when the mouse is over a bar chart. On the x-axis to reduce visual clutter we opted to use country codes instead of the full country names, however, this name is presented in the tooltip.

The **Sankey diagram** shows the flows from origin to destination with the nodes containing the names of these locations. The flows are interactively linked with the flow map so that hovering over a flow path highlights this flow path not only in the Sankey but in the flow map as well. Further interactivity in the flow map presents a tooltip which shows similar information in the flows i.e. x% share moves from country A to country B. A limiting factor in implementing the Sankey diagram using the library used in D3.js is that the placement or position of the nodes could not be easily manipulated to have the resource owners and fleet owners as the first position, processing locations as the second position and markets as the last position usually referred to as an alluvial Sankey diagram. The reason this could not be implemented is also due to the fact that the library could not easily allow for duplicate nodes e.g. Japan appears as a resource owner, fleet owner and market ideally it should appear at the three different positions in the Sankey however with limited technical capability this customization could not be implemented.

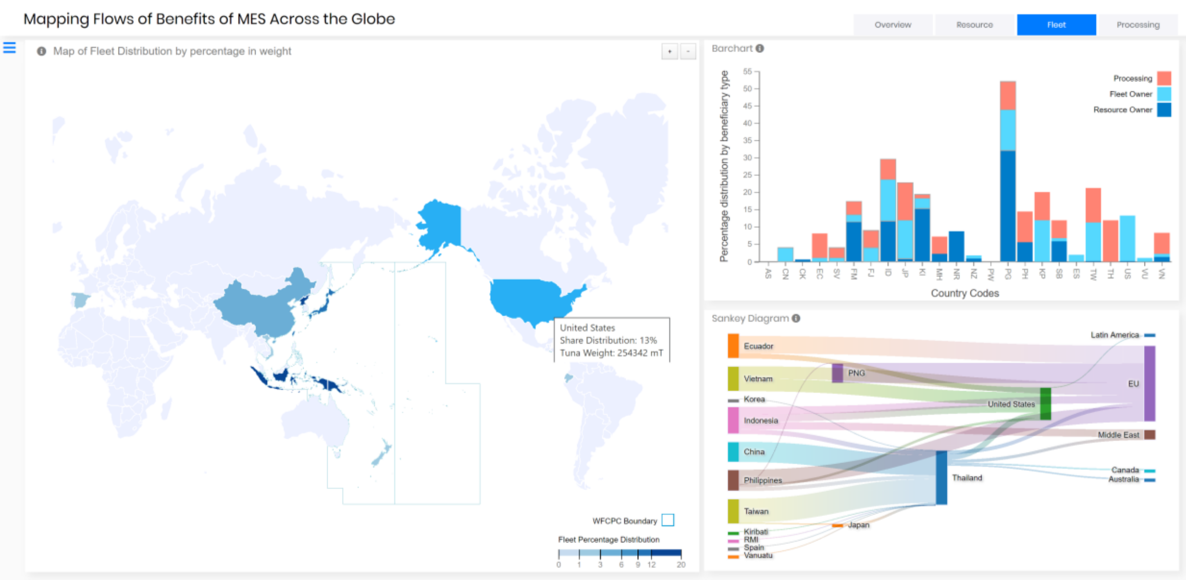


Figure 54: Illustrates the Choropleth map in the map panel upon selecting fleet

The map panel as described in the design allows for changing the view from flow map to **choropleth maps** which depict the % distribution by beneficiary type. Figure 54 demonstrates the choropleth when the user clicks on the fleet button. Based on visual design principles and recommendations from the usability testing the number of classes chosen to represent the distribution is 6 classes to reduce memory load. Placing the mouse over the country displays a tooltip with details about the country in that segment e.g. the %share distribution mapped for the United States is 11% and this is based on tuna fish caught by weight in metric Tons which is 254342 MT. Other choropleth maps for processing and resource are like the map displayed in Figure 54 and are accessible by clicking the respective buttons.

The final graphic that was implemented is in the bar chart in the **search panel** in the information menu. The information menu can be accessed by clicking on the menu icon at the top left corner. This contains the 5 menu panels about, legend, search, help, and information. The search panel allows users to search the country name of interest by typing in the search box which auto-populates the search value. The search result returns the country information details under each segment and a bar chart of the data for each segment as shown in Figure 55. The bar chart is mainly used for comparison to understand the main role that country plays in the global value supply chain of tuna fish within the WCPO region. Other menu items as described in the design are illustrated below in Figure 56.

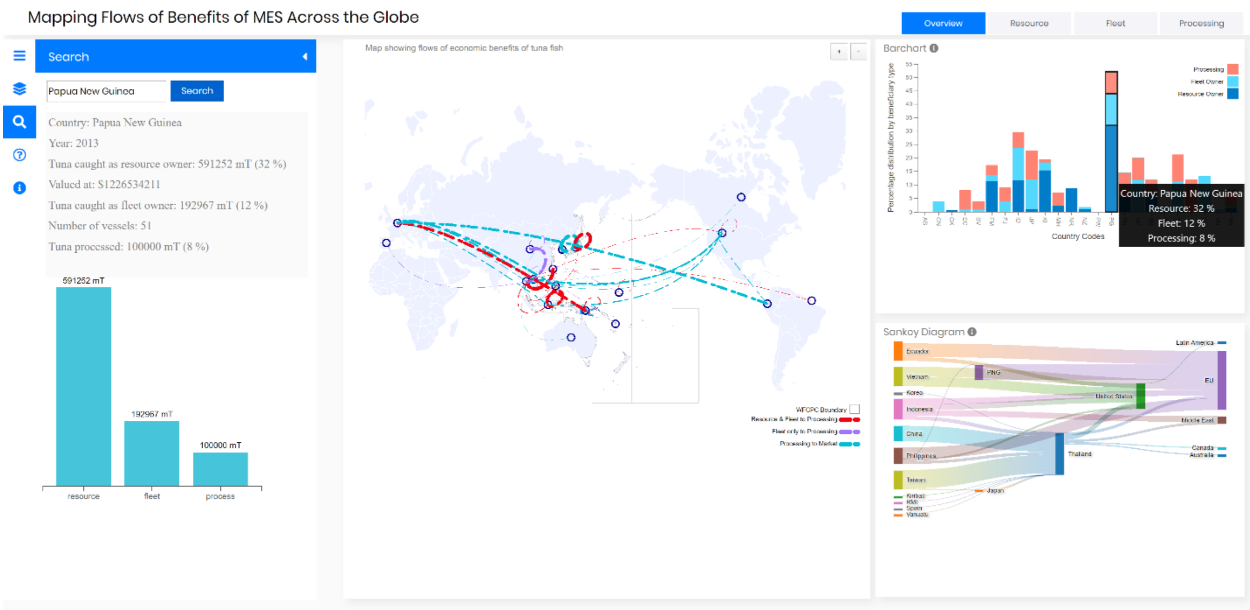


Figure 55: Search panel results visual illustration

Affordance is crucial in an interactive web application design and implementation. It follows Norman, (1988)'s principle to make things visible or what is obviously clickable. In the implementation several affordances were provided such as the use of buttons with different colours to indicate which button is active, switching mouse cursor from pointer to hand on a clickable item, using information icons to describe use and content displayed, using highlight over the map to show which country the user is hovering over or having a muted information in the search menu panel, "search name of the country", for users to understand that they can type in a country name to search for its details. These among other affordances based on general conventions make the interface easier to use and understand.

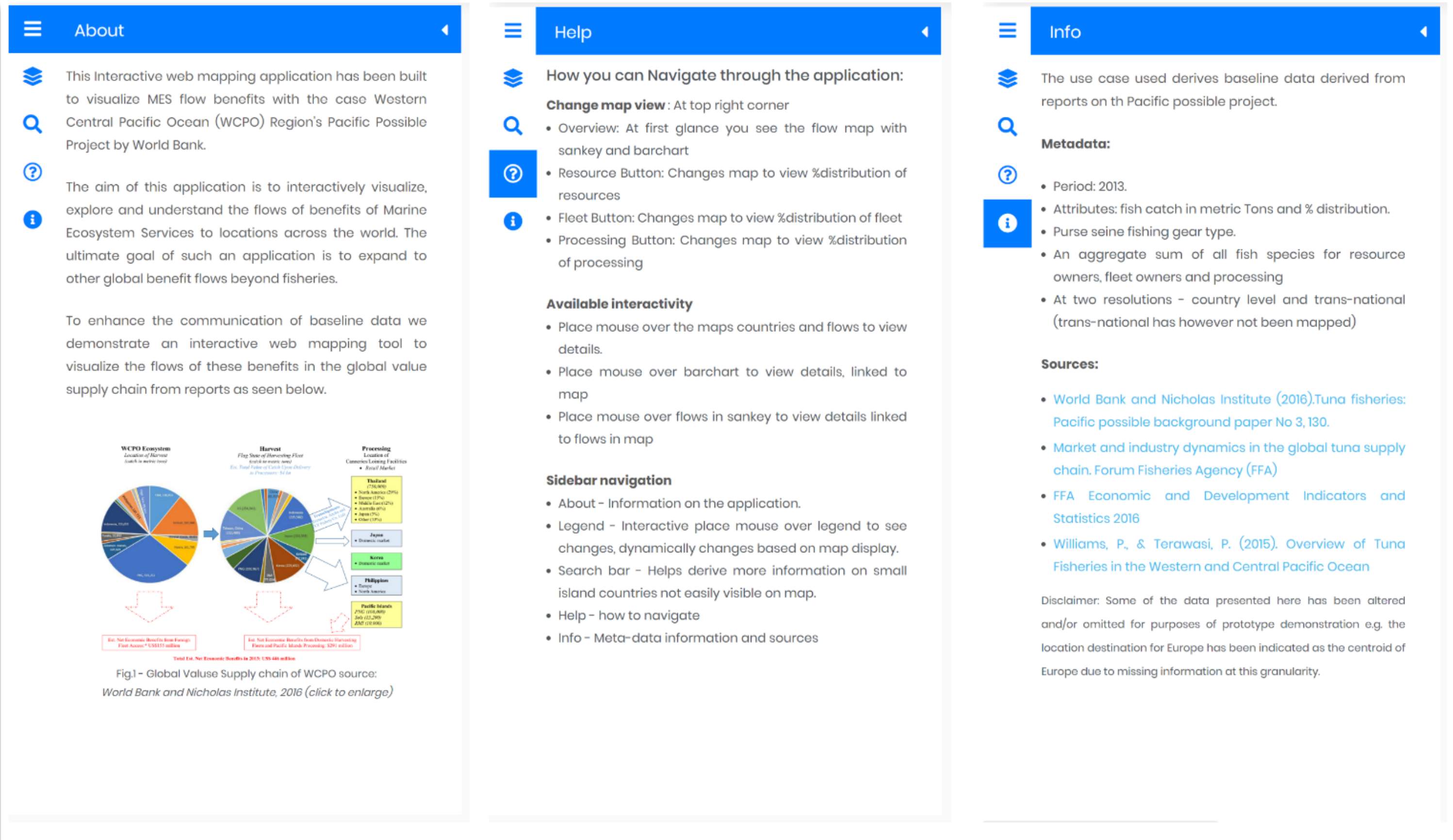


Figure 56: Menu Items in the Information Panel - about, help and information (legend menu item has not been shown here)

In conclusion, the demonstrated application tried to meet most of the requirements from the conceptual design framework. There were a few limitations due to technical capabilities which resulted in opting out of the functionality or trying alternative solutions such as in the Sankey. Figure 54, Figure 55 and Figure 56 demonstrate the User Interface implementation, to visualize the actual interactions or User Experience a video demonstration is made available at https://bit.ly/MESFlowMap. Screenshots to other types of interactivity discussed are presented in Appendix D.

4.3.4. Code versioning and Deployment

As presented in the methodology, it is important that at every step of the application development to use a version control system such as Git to keep track of the changes and have a history of various versions. This allows the developer to revert to an older version in case errors are made and the code is broken to the extent that it cannot be fixed. GitHub is also used as a remote repository to store all the code implementation and the versions. The code to the application is published on GitHub at (https://bit.ly/3cyxPBu). During this phase, the development was carried out in the student GIP server provided by ITC Faculty, University of Twente. This server is however not public which was important for the next phase of the research, usability testing. The application was thus zipped and deployed in a public-facing server and the link to this application is provided hence available at (https://kartoweb.itc.nl/students/wcpo/.

4.4. Empirical Evaluation (Usability Testing)

Usability testing was carried out in the month of May with 5 test participants. A summative evaluation of the prototype was done using online surveys, where the task-based analysis was the method chosen as described in section 3.8.1 with the use of questionnaires and interviews/discussions. The design of the experiment was described in methodology (section 3.8.2). The execution and results are described herein the following sections describing the hypothesis formulation, execution, and analysis of results. Then meta-evaluation and reflection of results are provided. This section addresses the fourth objective of the research, "*To test the usability of the prototype application with selected end-users*".

4.4.1. Hypothesis Formulation

To test the interactive web mapping application for the case of the WCPO project, a scenario is hypothesised based on the chosen users and user goals described in the user requirements and persona profiles. The scenario shown below was used:

> "The Pacific Possible project from the World Bank would like to understand the benefits of tuna fish that are realized in different parts of the world for the economic benefits of the purse-seine fishing gear type. A visualization was requested by the management team to help understand these benefits. The visualization was created to illustrate: The type of benefits realised i.e. resource (fish) owners, fleet owners, and processing plants (The final market distribution has not been explicitly mapped; however, market destination from processing locations is shown.). It also illustrates the distribution of these benefits across the globe and the flows of these benefits from one location to the next.
>
> Your, task as a user is to answer the task-based questions from the management team using the visualization tool. The aim is to determine if the application can help achieve the following goals:
> - To have a general view of beneficiary distributions in each segment.
> - To find out distribution per different types of benefits (resource, harvest, and processing).
> - To discern detailed information of the beneficiaries.
> - To see the relationship between those locations and understand the movement and direction of these flows.

The hypothesis of this test would be to determine ***if the application can help achieve most of the goals that the user aims to achieve through accomplishing the test task.*** For this purpose, sample questions were designed in the methods (section 3.8.2), and user testing was executed to prove the hypothesis true. For this research I expected a success rate of at least 75% of the task-based questions to be answered correctly to prove the hypothesis true.

4.4.2. Execution of Experiment

The evaluation was conducted with test participants or users performing the tasks using a working prototype. This was done through an online survey with both experts and non-experts for the chosen scenario. The approach included:

- Interviews using a real user to perform certain predefined tasks
- Questionnaires (both open and closed questions)
- Thinking aloud as the user tried to achieve the task
- Note keeping during the process
- Interview/Discussions

A semi-structured questionnaire based on the experiment design (Table 16), was prepared with questions for the interviewee's profile and for tasks to perform (see Appendix A). The summative online survey was carried out between 7th and 15th May where 11 users were contacted before this to ensure that the minimum target of 4 test participants with at least one project expert would participant. The outcomes resulted in 5 test users participating in the survey with 3 experts and 2 non-experts. The procedure involved having a 1hour Skype session with a brief introduction to the purpose of the survey and how to use the application, followed by the actual survey and interview. The questionnaires were divided into 3 parts: the tester's profile, the task-based analysis questions focusing on efficiency and effectiveness, and satisfaction as designed and a brief interview discussion on general feedback and comments of the visualization. Efficiency and Effectiveness were measured as demonstrated in Table 27 below:

Table 27: Measures of usability; Effectiveness and Efficiency

Efficiency **(Time resource expended in answering the question)** **How much time did it take?**	**Effectiveness** **(Tasks completeness with error rate)** **Was the question answered correctly?**	**Efficiency** **(Fatigue, productive-time ratio, or cognitive ability to answer)** **What was the level of difficulty of the task on the user?**
0 – 10 sec	Yes	Low
10 – 50 sec	Answered with help	Medium
Above 50 sec	No	High
	Not answered	

During the session, the test participant would share their screen to allow the interviewer to observe their actions as they try to achieve the question and they would also speak out loud in the execution. The interviewer would do note-taking and observations on the user's actions to note-down key issues that arise. The interviewer would also fill the information on the table above for each question. Upon completing the tasks, a 10-minute discussion on general overall feedback would follow with note keeping.

4.4.3. Analysis of Results

This section presents the results starting with the tester's profile and how it may influence the use of the application, then the task-based analysis, and the overall feedback. The tasks were formulated to target usability issues per visual graphic produced to uncover problems in the use and functionalities of each. The results of each participant were recorded and attached herein. (see Appendix B).

A. Tester's Profile

The survey was carried out with 5 test participants for the experiment with their ages ranging from 18 to 50 years, they had varying background fields where some were related to this research domain including ecosystem service, the case project, or geospatial web mapping. They also had varying levels of expertise in terms of the use of interactive web maps. Table 28 shows the outcomes of the survey conducted.

Table 28: Tester's Background Profile

Test Participant	Age	Education Level	Educational Background	Profession	Expertise
TP 1	35 – 50	Doctorate	Marine Policy	Director of Ocean Policy Program	MES Expert
TP 2	25 – 35	Masters	Agriculture, Gender and Development Studies	Research and Climate Action Project Coordinator, CIAT	Non-expert
TP 3	18 – 25	Masters	Geoinformatics	GIS Analyst, student	Web-GIS expert
TP 4	25 – 35	Masters	Biosystems Engineering, Water and Sanitation	Research and Development Engineer – Water purification systems & technologist	Non-expert
TP 5	35 – 50	Doctorate	Ph.D. and MSc in Soil Science	Assistant Professor in Ecosystem Services and Land-use change	ES Expert

The profile shows a mix of both experts and non-experts related to their educational and professional backgrounds with the domain of the case study and research field. This meant that a brief introduction to the use of the research had to be done regardless of expert or not.

Table 29: Tester's Expertise Level by technical, domain and use case knowledge

TP	Technical Expertise			Domain expertise	Use Case Knowledge	
	Using Maps	Interactive Maps	Interactive Map functions	ES/MES knowledge	The familiarity of the Pacific Possible Project	Involved in Project
TP 1	No	No	No	Yes	Yes	Researcher for a series of economic reports
TP 2	Yes, somehow	Yes	Yes	No	No	n/a
TP 3	Yes, high level	Yes	Yes	No	No	n/a
TP 4	Yes, somehow	Yes	Yes	No	No	n/a
TP 5	Yes, high level	Yes	Yes	Yes	No	n/a

Another important aspect is the technical expertise, domain expertise, and use case knowledge. This enables us to understand how different users would understand or interact with the application. In-depth feedback with regards to the specific domain, expertise was expected from experts. Monitoring the general ease of use for non-experts was also important to understand how easy it is to use the application for non-experts. In this regard, the latter questions in the tester's profile looked at these aspects as depicted in Table 29 above and Figure 57.

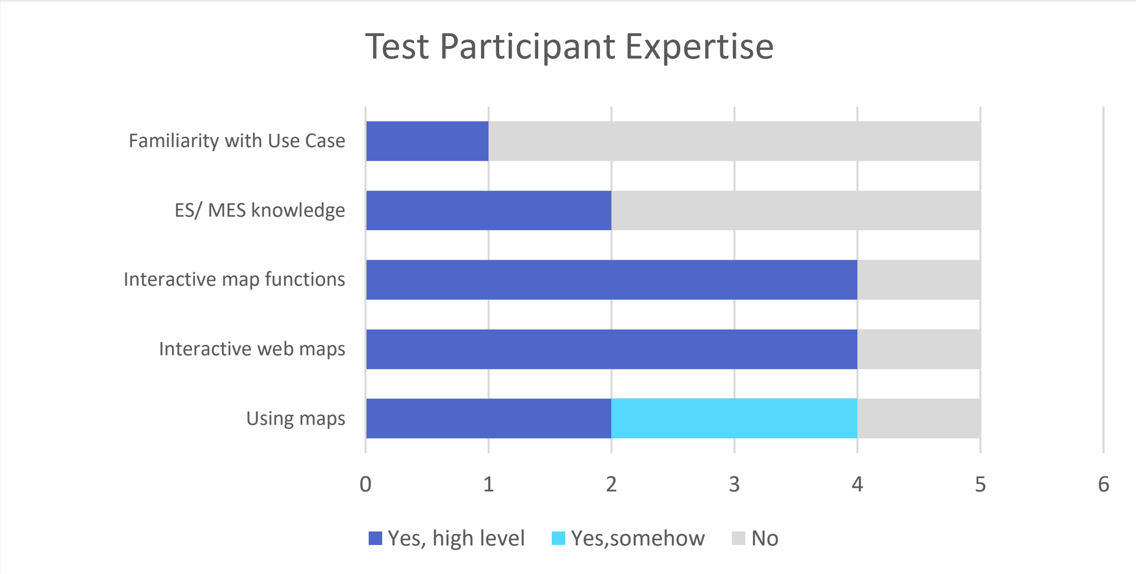


Figure 57: Level of Test Participants' expertise by domain, use case, and technical knowledge

B. Task-based analysis – Efficiency and Effectiveness

The second part of the questionnaire tests the effectiveness, efficiency, and satisfaction of the application based on Table 27. We use the sample questions designed in the experiment to test the effectiveness and efficiency of the application as well as inferred satisfaction. Table 30 below provides an indicative summary of the average score measure for all the participants with general comments and observations when tackling each task. The individual results of each test participant are provided in Appendix B. Each of the questions was designed to target specific visualizations and actions in the web application. The measures of testing included time, the measure of accuracy, and measure of difficulty.

Table 30: Test Participants' Average Results on Effectiveness and Efficiency Testing

Questions	Avg. Time	Accuracy	Difficulty	Target Visual	Comments/Suggestions
1. What is the largest benefit type of Papua New Guinea with country code PG?	10-50	Yes	Low	Bar chart & Flow Map	It does not understand what %share means. Make the axis clear What is "dist" short form for?
2. What is the weight in % share distribution of tuna fish caught by Micronesia with country code FM as a resource owner?	10-50	Yes	Low	Bar chart & Flow Map	The meaning of the values is ambiguous; Explain the data and why %share is used.

3. What countries does Taiwan export tuna fish to for processing?	10-50	Yes	Medium	Sankey Diagram & Flow Map	Direction using animation is appreciated to be quite effective
4. Which regions do most countries export processed tuna to for consumption (market)?	Above 50	No/Wrong	High	Sankey Diagram & Flow Map	Using Russia as the centroid of Europe brings ambiguity and is confusing to domain experts. Preferably shift to the capital of the European Commission instead (Brussels). TP2 does not understand if the question refers to using Sankey or flow map and confused by the Sankey positions. Not sure what the centre of Russia means, should I look at how many flows are moving or the Sankey? The user does not understand if the question wants the largest or all. Why are there countries that are not connected to Sankey?
5. Which is the largest processing location of fish by weight in metric tons?	10-50	Yes	Medium	Distribution Maps	Confusion on the discrepancies of the data itself e.g. some countries have %share but 0 value in metric tons which is not logical. Suggests replacing 0 values with no data/ missing data. Not very easy to just keep hovering over the maps due to small countries. Not sure whether to hover on all, my next best option is to use a bar chart. Quite clear, but colours variations might be too many.
6. Which country has the highest percentage of fleets fishing in WCPO?	Above 50	Yes	Medium	Distribution Maps	% share compared to metric tons not clear. Not very easy to just keep hovering over the maps due to small countries. Rename Papua New Guinea to PNG in the search
7. What is the main way that China benefits from tuna fish of the WCPO region?	10-50	Yes, answered with the help	Medium	Search	The user could not scroll to see the information at the bottom. Very good search tool. Link it to the map to zoom or highlight the country

8. Name one county which processes tuna and consumes it domestically (processing to market), closed-loop interactions.	Above 50	Yes, answered with the help	High	Flow Map	The user could not scroll to see the legend. Terms used in the values supply chain resource, fleet, process to market could be explained. A bit confusing because of overlapping flows. Adjust so that filtering can be fixed on one type of flow when clicked not mouse hover. Confusing because there are two colours in Japan. TP can see that Japan is both red and blue, can be a bit tricky but that is good that you can toggle the flows. Provide explanation to allow toggling

Accuracy – To test accuracy we measure the ability to achieve a task or answer the questions correctly. This enables us to see which visualizations have more issues in arriving at the correct answer and what usability issues overall arise in the general understanding of the visualization (Figure 58). From the graph below we can see that question 4 had a major challenge with answering the questions correctly. Based on the comments from TP3 " I do not understand if the question wants the largest consumers" and "the Sankey positions are confusing to know where market and processing is." and TP4 "Not sure what the centre of Russia means, should I look at how many flows are moving or the Sankey?" it could be concluded that the question was ambiguous as the TP did not know whether to choose only two largest or all locations that are market. From the observations of TP2 and TP3 who says " I am confused by the Sankey positions", it can also be understood that the positions of the Sankey nodes resulted in ambiguity as to which position refers to processing and market.

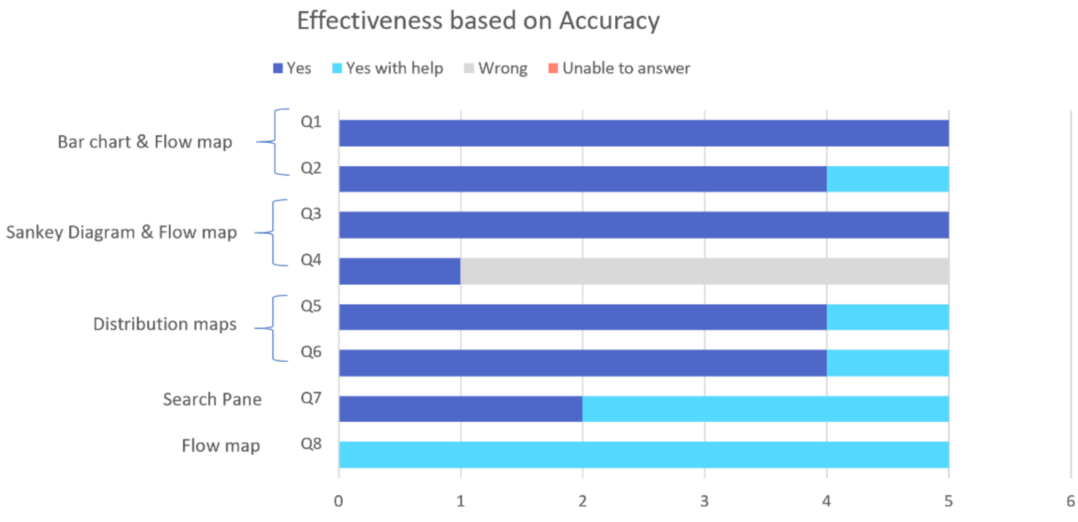


Figure 58: Graph of measure of effectiveness based on accuracy by visual component per task

Difficulty – In determining difficulty we chose to measure how easy to difficult a task was to solve i.e. low to mean quite easy and high to mean very difficult (Figure 59). The tasks formulated had different levels of difficulty, starting with the easier questions which allow for the early success of the test participant and encourages them to carry on. In the context of difficulty, question 8 that references the flow maps with regards to closed loops proved to be the most difficult question. One main issue or challenge that arose was that it was difficult to hover over the small maps. Another was that most TP's forgot the about the function to hover over the legend to filter flows hence needed help. TP5 suggested having a description to indicate toggle. TP 4 also suggested additionally adding on and off checkboxes to toggle layers as opposed to hover. It should also be noted that the chosen implementation meant that if two types of flows exist in the same country e.g. resource to processing and processing to market, one would be drawn on top of the other and obscure it hence it would only be visible by filtering. This could potentially bring challenges in interpreting the data.

Questions 5 and 6 that focused on distribution maps also proved to be moderately difficult and one factor was that most TPs forgot that one can switch between maps using the buttons. Another reason was that it required much effort to constantly hover over each country to determine values. TP 3 mentioned the importance of bar chart here as the next bet to help answer correctly. TP 5 also suggested reducing the number of colours used in the distribution maps (i.e. reduce the number of classes). Question 7 on the search pane also resulted in some technical issues as two test participants were not able to scroll to the bottom to see the information presented and this meant that they had to result in using the bar chart to answer the question instead of the search pane. For this reason, TP1 suggested adding a scroll functionality to the application for users with different size screens.

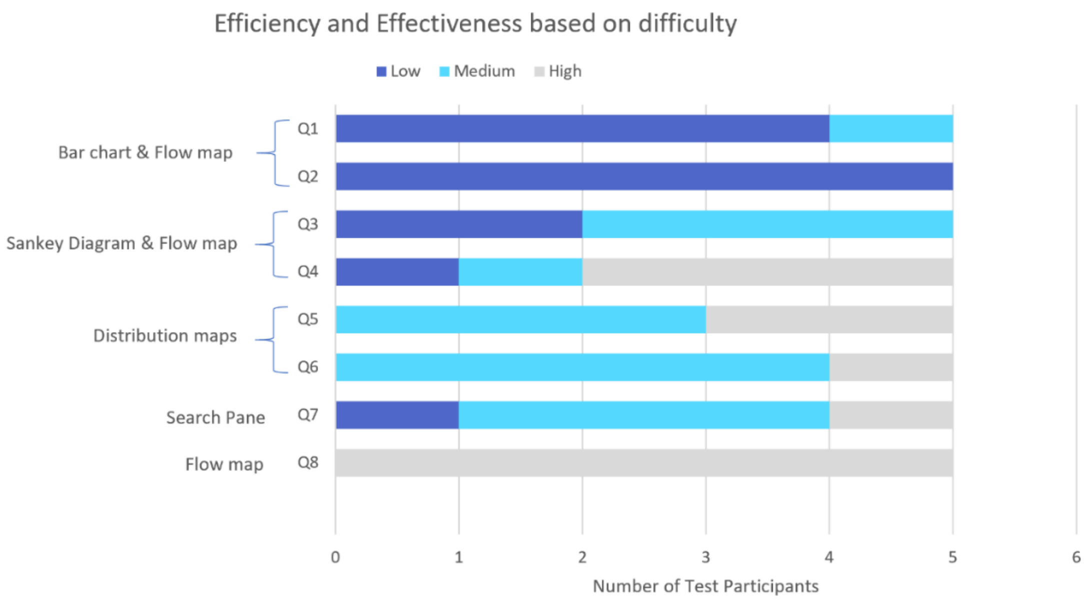


Figure 59: Graph of measure of effectiveness and efficiency based on difficulty by visual component per tasks

Time resource expended(efficiency) - Time was measured in 3 categories (0-10s, 10-50s, Above 50). This enables us to determine the efficiency in time and productive-time ration, it also helps to indirectly infer fatigue and cost-effectiveness. It should be noted that the method chosen for the survey was think-aloud which does not allow a user to naturally perform tasks as they normally would since they have to speak their thoughts while they achieve tasks. This means that the tasks possibly recorded more time than would have taken them under a normal environment. Nonetheless, some tasks were clearly easier to accomplish within a short time than others (Figure 60).

Question 8 undoubtedly took the longest time to answer due to the afore-mentioned reasons such as difficultly in answering and memory fatigue in trying to remember available functionalities such as filter or toggle. The question was also complex and needed some time to understand. The fact that there were two overlaying colours for Japan also confused TP4 who took a longer time to understand this. Question 4 also took 3 out 5 of TP's quite some time since they did not understand the question. This resulted from the question being ambiguous as it was not easy to understand the needed outcome. Question 6 also proved to take quite some time as several TP's forgot that one can switch between distribution maps using buttons and that that one needed to hover on most of the countries. This could be improved by reducing the number of classes to reduce the number of shades available.

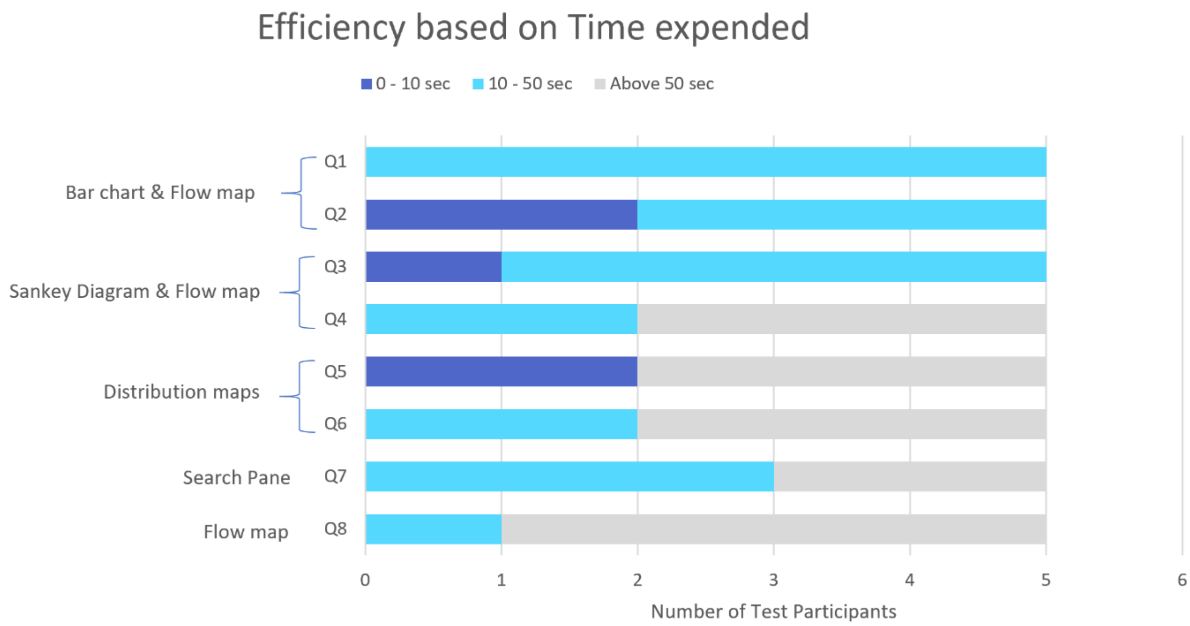


Figure 60: Graph of measure of efficiency based on time resource expended by visual component per task

C. Satisfaction

Part II of the second section entailed a set of questions to discern the satisfaction of the visualizations. Satisfaction was also derived from the interview discussion where general feedback was provided on the overall use of the application. The results of the satisfaction were averaged in Table 31.

Table 31: Average results of satisfaction testing

Question	Target Visualization	Average Rating / Result	Comments
1. Is the visualization misleading/ ambiguous e.g. does it convey confusing information?	Overall	4/5	Data discrepancies are somewhat misleading in distribution maps where weight in 0 MT is has a percentage. The meaning of %share in the bar chart is also confusing. Explain legend and axis A clearer title would be best by adding a sub-tile that is more descriptive
2. Is the choice of colours suitable?	Overall	5/5	Consider reducing the number of classes in too many colours. Check on the colours of the Sankey diagram to distinguish red and green for colour blindness. Some countries have the same colours
3. What is the best use of this visualization?	Overall	Both General overview and detailed information	The majority of the users thought that it allows visualizing both a general overview and detailed information.
4. How easy is it to use the visualizations?	Overall	Simple and easy to use	With brief descriptions on how to use the application, it is rated simple to use.
5. Which visualization did you find more straightforward, easy to understand?	Flow Map	4	Great use of animation for direction. Flows are very clear and intuitive
	Bar Chart	5	Requires explanation on the axis and data
	Sankey Diagram	4	Explain placement
	Distribution Maps	4	Reduce the number of classes Ambiguity in data values e.g. Japan's 0MT has an 11% share.

Overall, most of the users were satisfied with the application. An average of 4 was rated for ambiguity due to some of the reasons given in Table 31 such as data discrepancies and provision of descriptions. As per the objectives described in the scenario, the average response was that the application can provide both general and detailed information. TP 1 states that the application is very suitable to provide fisheries management and policy with a holistic picture and see who the key beneficiaries are. TP1 also states that it is good to enable underlying data only in some cases when necessary. TP4 reiterates the point that it is suitable for making decisions on what each country's role is in the tuna fishing industry for that region. TP5 mentions that it is suitable for a general overview and that detailed information would need a short training on the use of the application. On average the participants explain that once they have been shown how to use the application, then it is simple and easy to use for solving tasks and meeting the end-user goals. The bar chart is rated the highest as it is seen to be the most intuitive and easy to read, however, explanation information should be provided for the y-axis and data represented. The flow map, Sankey, and distribution maps are all rated 4 with the underlying issues already mentioned throughout the testing.

D. Interview and Discussions

The last section covered general feedback based on a short interview. The discussions took 10 minutes and it was based on 2 sets of open-ended questions: Any suggestions for improvements? And Are all functionalities useful and what could be removed? A discussion on what the test participants thought overall about the use of the application was noted down and some of the points that had been previously mentioned in the task-based analysis but were re-iterated. Other general comments were also given. The overall feedback and suggestions for improvement include:

1. Data discrepancies data in distribution maps.
2. The terminology used in the fisheries value chain can be a bit confusing, explanation on the terms used would help. e.g. distinguish resources from the fleet. This can be in the about or information section.
3. Change the location of Europe to EU Commission capital (Brussels).
4. Explain the meaning of % share distribution in the y-axis of the bar chart.
5. Information on about section should state the mapped data is a part of the report on the economic benefits from purse seine fishing gear in WCPO not for the entire project.
6. Fix scrolling issue to optimize for screen sizes.
7. Arrangement and placement of country nodes in Sankey could be explained and be based on the attributes.
8. Remove unlinked country nodes in the Sankey diagram.
9. Enable panning in the maps, not just zoom.
10. Filtering flows on mouse over legend could be replaced with checkboxes to toggle on and off and make it fixed. So that the flows remain static and one can hover over only filtered flows.
11. Include sub-title to make the application more informative at first glance
12. Add map titles to the different maps.
13. The projection centre of the map is confusing as the TP is used to map centred on GMT.
14. Check on the colour combination in Sankey for colour blindness.
15. Reduce the number of shades of blue (classes for the distribution maps).
16. Placement of the button above the bar chart can be confusing and could be placed above the map.
17. Panels for the map could be made larger and for bar chart and Sankey reduced.
18. It may be informative or great to add fishing or ecological boundaries such as EEZ's

All users stated that all tools and functions in the application were quite useful and served the purpose well. Concluding that the application was well built for the purpose and intended audience. TP1 said that the application was very aesthetically pleasing and intuitive to use, they liked the affordance of direction which was provided by the use of animation and very much liked that the flows and Sankey were linked to better see the relationships. TP1 concluded that the application is suitable for intended purpose "it would help fisheries managers to understand the key players and their role in the tuna fish industry".

TP2 also commented that the application is useful to understand general information on the global supply chain of tuna fish. While TP3 stated that the visualizations are beautiful and quite useful and commented that the Sankey diagram was a very quick way of understanding the relationships in the flows. TP4 restated what has previously been mentioned and added that the search functionality is very useful to determine detailed information. TP4 also mentioned that the application is relevant in current business and supply chain management and that other product chains should investigate reproducing such interactive web applications in their supply chain management workflow.

E. Meta-Evaluation and Reflection on Usability Results

In conclusion, the survey carried out through task-based analysis and interview discussions uncovered several usability issues. Effectiveness, efficiency, and satisfaction measures showed some key areas for improvement of the application. The issues deduced can be categorised based on the targeted visuals as listed below:

Bar chart

1. Avoid the use of short forms; "dist" in the tooltip.
2. Describe the y-axis with an information icon. Users do not understand what %share means.
3. The meaning of the values is not clear. Explain the data and why %share is used in the information menu.

Distribution Maps

1. Data values are misleading where 0MT has a value in % share. Consider replacing 0 with missing data or no data.
2. Check on data accuracy and if the data is ambiguous explain this in the information panel.
3. Not very easy to just keep hovering over the maps due to small countries.
4. Too many shades of blue to discern the highest value. Consider reducing the number of classes.

Sankey Diagram

1. Why are there countries that are not connected or not linked? Check to see if there is error in data.
2. What does the placement or arrangement of countries mean? The arrangement and placement of country nodes in Sankey could be explained and be based on the attributes.
3. Check on colour combination in Sankey for colour blindness.

Flow Map

1. Using Russia as the centroid of Europe brings ambiguity and is confusing to domain experts. Consider changing the location of Europe to EU Commission capital.
2. Explain the ability to toggle flows by hovering over legend.
3. Fix legend filter to allow clicking on and off. Mouse over legend could be replaced with checkboxes to toggle on and off and make it fixed.
4. Clearly define WCPO fishing boundaries.

Search Pane

1. Rename Papua New Guinea to PNG in the search.
2. Very good search tool. Link it to the map to zoom or highlight the country

Overall/General Issues

1. Fix the scrolling of the application to optimize for different screens of different users.
2. Enable panning in the maps, not just zoom.
3. Include sub-title to make the application more informative at first glance.
4. Add map titles to the different maps.
5. The projection centre of the map is confusing as the user is used to map centred on GMT.
6. Placement of the button above the bar chart can be confusing and could be placed above the map.
7. Panels for the map could be made larger and for bar chart and Sankey reduced.
8. It may be informative or nice to add fishing or ecological boundaries such as EEZ's.
9. Information on about section should state that the mapped data is a part of the report on the economic benefits from purse seine fishing gear in WCPO not for the entire project. Check on the introduction statement.
10. The terminology used in the fisheries value chain can be a bit confusing. Explanation of the terms used would help. e.g. distinguish resources from the fleet. This can be in the about or information section.

In retrospect, it is quite evident that the chosen methods for usability testing uncovered many issues as previously expected for the think-aloud method (Nielsen, 1992). Nevertheless, without considering time and difficulty levels the success rate of achieving the task correctly was 87% and most of the users stated that the application is useful to meet the objectives of the end-user. For this reason, we prove the hypothesis true for the user testing and conclude that the application met most of the criteria set for usability and can be said to be useful for the use case purpose. These issues are then used in the adaptation and final implementation of the prototype before the final review by the expert test participant.

4.4.4. Adaptations and Implementation

The purpose of usability testing is to determine if the web application meets the needs of the end-user and to uncover issues that may be used to adapt the prototype. These would be useful to adapt the prototype to be efficient, effective, and provide satisfaction. From the feedback, adaptions, or solutions to these usability issues may have been suggested or indirectly inferred. These adaptation solutions are hence discussed. Table 32 focuses on specific components or visual graphics in the application and Table 33 gives the general adaptations for use of the application. The last column indicates whether these solutions were implemented or if the suggestion was not implemented in which case an explanation is provided under solutions or alternatives.

Table 32: Addressing usability issues with adaptations specific to visual components

Target Visual	**Actions/ Function**	**Comments/ Suggestions for improvements**	**Adaptation solutions or alternatives**	
Bar Chart	Axis information	Provided clear y-axis description. What is %share?	Change label of the y-axis to be something more appropriate such as "Percentage Distribution by beneficiary type"	✓
	Axis information	Describe the y-axis with an information icon.	Provide information window in bar chart further explaining this.	✓
	Bar Tooltip information	What is "dist" short form for? Avoid short forms.	Use "distribution" or remove it.	✓
	Data represented	Explain the data represented and why %share is used in the information panel.	Provide an information icon for the entire bar chart data.	✓
Distribution Maps (Choropleth Maps)	Data represented	Data values are misleading in relation to % share e.g. Japan has 0MT in weight and 11% share in processing	This issue arose due to missing data where the only %share was used to visualize. Can replace 0 with missing data or no data where 0 has a value in %share	✓
	Data represented	Check on data accuracy of the data if it is ambiguous to explain in the information panel.	Verify all data with the original. Explaining missing data within the application menu in the info item.	✓
		Not very easy to just keep hovering over the maps due to small countries.	An alternative has been offered using the bar chart.	✓
	Classes used in choropleth	Too many shades of blue to discern the highest value.	Reduce the number of classes from 8 to 6	✓

		Consider reducing the number of classes.		
Sankey Diagram	Data and representation	Why are there countries that are not connected or not linked? Check to see if there is error in data.	Check to see duplicated data and remove them.	✓
	Placement	What does the placement or arrangement of countries mean? The arrangement and placement of country nodes in Sankey could be explained and be based on the attributes.	The position of an alluvial Sankey-diagram should be dependent on steps or attributes. However, this proved to be a challenge to implement using d3 due to inadequate technical know-how and time.	✗
	Colour	Check on colour combination in Sankey for colour blindness.	Check for colour blindness and remove either red or green or use a different colour scale. Red can be removed from d3.schemeCategory10	✓
Flow Map	Logical representation	Using Russia as the centroid of Europe brings ambiguity and is confusing to domain experts.	Change location of Europe to EU Commission capital i.e. Brussels	✓
	Legend filter function	Explain the ability to toggle flow layers by hovering over legend.	Add small description above for hover or click to filter legend to offer affordance.	✓
		Fix legend filter to allow clicking on and off. So that the flows remain static and one can hover over only filtered flows.	Filtering flows on mouse over legend could be fixed instead of having mouse-over function, instead, use click function which is a fixed action until the user clicks on somewhere else outside the map.	✓
		More clearly defined WCPO fishing boundaries.	WCPO Boundary colour could be made darker.	✓
Search Pane	Data in search	TP could not find Papua New Guinea because it is written as PNG.	Rename Papua New Guinea to PNG in the search.	✓
	Linked views	The search result could be more useful if it were linked to the map.	Link search results to the map to zoom or highlight the country. This was partially met where highlight by search functionality was included, however, zooming function was removed due to technical issues challenges with resetting the view back to the global extent.	✓

Table 33: Addressing usability issues with general adaptations to the web prototype

Target Functions	Comments/ Suggestions for improvements	Adaptation solutions or alternatives	
UI Layout	Fix the scrolling of the application to optimize for different screens of different users.	Add scrolling overflow on the y-axis of the application	✓
Map Functionality	Enable panning in the maps, not just zoom.	Add a panning button. Not implemented due to technical challenges in the code.	✗
Descriptive Information	Include a subtitle to make an application more informative at first glance or describe maps.	An alternative solution is where descriptive map titles were included for each map and description provided in about section	✓
Map Elements	Add map titles to the different maps.	Add map title to each of the 4 maps e.g. "Map of Flows of tuna fish in the supply chain", "Map of resource distribution by %share", "Map of fleet distribution by %share" and "Map of processing distribution by %share"	✓
Map Composition	The projection centre of the map is confusing. The test participant is accustomed to maps that are centred on GMT.	This shall not be changed as the geographic centre has been chosen to be the Pacific Island countries which align with the maps of the target end-users. It also places the focus on the use of the case study.	✗
Placement/UI Layout	Placement of the button above the bar chart can be confusing and could be placed above the map.	This shall not be changed as the placement has been decided based on principles of visual design where items in the top left corner have a higher weight to allow users to see them. If it is placed above the map as suggested by TP5 it would cause visual clutter in the map with map titles and navigation tools. Moreover, TP1 and TP3 mentioned the buttons offer intuitive affordance and are easy to navigate to.	✗
UI Layout	Panels for the map could be made larger and for bar chart and Sankey reduced.	Reducing the size of the bar chart and Sankey to accommodate the map.	✓
Map content	It may be informative or nice to add fishing or ecological boundaries such as EEZ's	Adding the layer with the ability to toggle on and off would be a great implementation. However, this may lead to information overload on the overview page and therefore for this reason was not implemented. Another reason was the time limit and technical skills required to implement was limiting.	✗
About descriptive information	Information on About should state the mapped data is a part of the report on the economic benefits from purse seine fishing gear in WCPO not for the entire project. Check on the introduction statement.	Adapt the description in the about page as mentioned by expert TP1.	✓

About/Information panel	The terminology used in the fisheries value chain can be a bit confusing, explanation on the terms used would help. e.g. distinguish resources from the fleet. This can be in the about or information section.	Explain the terminologies used in the information or about sections	✓

In this research, we tried to adapt the application to address the majority of the usability issues mentioned. However, due to time and technical capabilities, some of these were not adapted and those considered to have a higher effect on the error rate were addressed. Other issues remain useful to consider however may be implemented in future adaptations. The final prototype was then adapted for the second round of testing.

4.5. Formative Evaluation – Second Round of Usability Testing

4.5.1. Design and Execution of the Experiment

The prototype was adapted and fixed for usability issues and the final prototype was then tested for usability with a focus on satisfaction. The second round of testing was carried out on 1st June 2020 with one expert user based on the formative evaluation. Only one expert was considered due to factors including time constraints and availability of test participants. However, I thought this to be sufficient to carry out the review with only one user if they have the minimum requirement of a case study expert and domain expert. For this reason, the test participant that met the criteria of a project expert was TP1 since based on the user profile they had previously been involved in the case study project, and TP1 also has a background in the domain of marine policy.

It entailed a short 20-minute online interview with one expert who is a use case project expert. TP1 would give feedback on whether the newly adapted prototype meets most of their demands and if it satisfies the user. The testing method chosen was an open-ended interview discussion guided by the questions designed in Table 34. This interview involved allowing the user to interact with the application to determine if some of the previously pointed issues have been fixed. The user would then answer a few open-ended. The sample questionnaire form used in the 2nd round of user testing is attached herein Appendix C. For the survey we state that overall aim of the prototype is "To communicate the flows of economic benefits of Marine Ecosystem Services across the globe for the case of WCPO purse seine tuna fisheries" and identify the related-use purposes for the prototype as:

1. To have a general view of beneficiary distributions in each segment.
2. To find out distribution per different types of benefits (resource, fleet/harvest, and processing).
3. To determine detailed information of the beneficiaries.
4. To see the relationship between those locations and understand the movement and direction of these flows.

Table 34: Formative Evaluation - Satisfaction Testing

Question	Measure
How would you rate the ease of use of the application after the adaptations on a rating of 1 to 5?	Ease of usability; Overall satisfaction
What are the general issues that you think still exist that are crucial for the end-user?	Discretionary usage Satisfaction with features
Do you think the application can help achieve the defined goal and use purpose? If no, why?	Goal and Use Purpose
Do you think this application may be useful for decision making in Marine Ecosystem Services? If no, why?	Domain Purpose
Which other areas would you suggest useful for reproducing such a visualization?	Boundary Conditions and Application Areas

4.5.2. Analysis of Results

The formative online survey was conducted in a 20-minute interview discussion. The interviewer restated the purpose and goals of the applications, outlined the usability issues that were previously pointed out in the first round of testing, and proceeded to explain which of the issues were resolved in what way and where were alternative solutions sought. The interviewee then explored the application and gave their feedback based on the designed questionnaire. The results of these are discussed in Table 35.

Table 35: Results of the Second User Testing

Question	Outcomes
How would you rate the ease of use of the application after the adaptations on a rating of 1 to 5	Overall, the test participant found this final adapted prototype much easier to use, intuitive, and quite comprehensive. TP1 gave ratings: Bar chart – 4/5 Sankey Diagram - 3/5 (explained that generally, Sankey diagrams are not easy for the TP1 because they have never interacted with one before) Flow map – 4/5 Distribution maps – 4/5
What are the general issues that you think still exist that are crucial for the end-user?	In general, everything seems great except for the description in the information icon for the Bar chart which was slightly misleading. TP1 suggested for clarity to rephrase the information icon, “The information in the bar chart needs to be defined clearly i.e. it is not a percentage of the global total but of the total of WCPO purse seine tuna fisheries. Therefore, you may rephrase it to the percentage of weight in metric tons for a country over the total

	WCPO purse seine tuna fish weight at each stage or segment in the value chain." A question that was raised was, "why are there were no segments for resource owners only?"
Do you think the application can help achieve the defined goal and use purpose? If no, why?	Yes, TP1 considers this to be a very useful tool for users to visualize the distribution of benefits and how global the value chain is interrelated. TP1 mentions that it will only be useful to address all purposes and for decision making if the data that gets inputted into the application is accurate and relevant. However, the current prototype does address all the use case purpose and end goal.
Do you think this application may be useful for decision making in Marine Ecosystem Services? If no, why?	TP1 mentions that this prototype is certainly very useful for marine policy and fisheries management. TP1 also identifies that it may be easier to visualize ES provisioning services as the metrics or observational values are easier to quantify. From a policy perspective, it would also be interesting in future research to view flows from resource owners only as this can attribute to decisions made by resource management. Where management would see how much volume is coming from resource ownership in comparison to fleet ownership. It would also be vital to see the large volumes of catch happening from foreign fleets in the waters of these resource owners. Another suggestion for future work would be to include the actual economic values. For resource owners, a distribution map of the percentage of access fees between resource owners or from the value of the Vessel Day Scheme (VDS) would be interesting information. For fleet owners what would also be interesting is to map the distribution of the "delivered value of catch" (landed value). This value may sometimes not be the exact value the fleet owner gets because they may use a trading company in between hence it is the value that the trading company gets when it delivers the product to the processor. However, it could be used as a proxy for fleet owners to show this price multiplied by the catch to have actual economic values.
Which other areas would you suggest useful for reproducing such a visualization?	Other application areas include: Reproducing this not only for purse seine tuna fisheries but incorporate other tuna fisheries and have a global map of tuna fish flows and benefits. However, this would only be feasible depending on the data available. TP1 suggests an interesting area for future adaptations in Marine Policy is from a Blue economy perspective. For a given area or country in the EEZ mapping of flows of economic benefits from different blue economy sectors such as fisheries, maritime, minerals and renewable energy or tourism would be vital to essentially show

	how globalized the blue economy is in a given country. Which would be valuable information for countries or regions seeking to develop their ocean spaces and build blue economy strategies.

Conclusions on the second Usability Testing

Based on question two on issues in the bar chart it should be noted that the total nominal weight at each segment is different i.e. they are not comparable for example the total metric tons processed is not comparable to the total metric tons caught by fleet or resource owners. Hence, we can say that we are only reporting a given % of the total at each stage of the value chain but comparing the totals from different stages of the value chain is not correct because they are not comparable since they have been transformed. Also to address the question on why we did not include a resource owner only segment, we explained that the data that resulted after carrying out the data inclusion criteria meant that most Pacific Island Countries that were resource owners only were eliminated as they did not have spatial relationships. However, ideally, the data should be representative of all stages in the supply chain. We argue that the visualization is as good as the data that is fed into it.

The discussions from question 4 on the usefulness of the prototype in MES for decision making, it is important to note and distinguish between beneficiaries versus benefits. Here for the visualization, we refer to beneficiaries in terms of volume of tuna fish weight mapped not in terms of value. It is suggested for future adaptations to add economic values for resource and fleet owner stage. However, right now for this research, it is done as a percentage distribution of the weight due to availability of data which acts as a proxy of the economic benefits, but future research could provide direct measures of these benefits by having actual economic values.

TP1 suggests other areas of adapting this application could be to focus on the different blue economy sectors. Blue economy refers to "the sustainable use of ocean resources for economic growth, improved livelihood and jobs, and ocean ecosystem health" (World Bank, 2017), hence it encompasses all the activities related to the use of ocean resources. Depending on data availability structure and feasibility of implementing this would be an interesting area of exploration for marine policy and decision making.

Overall, the 2nd round of usability testing though qualitative was quite informative on the usefulness of the application and its applicability in other areas. It informed us that the prototype sufficiently met most of the user's requirements and that most usability issues were resolved. We adapted the final prototype to address the remaining usability issue on the description of the bar chart. Then we deployed the adapted application in a public-facing server. The final implemented prototype can be accessed through this link: https://kartoweb.itc.nl/students/wcpo/. This survey also gave some insightful feedback for discussions on the use of such applications in other areas, and what type of data could be visualized in future research work to provide even more informative use of the application for policy and decision-makers. The discussions on limitations and suggestions for future works are presented in chapter 5.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion and Research Outcomes

The research presented here centres on two domain areas: ecosystem service mapping and the field in cartography of mapping branching origin-destination data. Maps representing ecosystem services flows generally try to depict a type of data in cartography that has been referred to as origin-destination (OD) data. Marine Ecosystem Services distant flows (MES) is a unique type of branching OD data that is inherently characterized by its highly dynamic nature and spatially distant relationships or spatial interactions. Maps that currently exist for ES and MES are static (Rühringer, 2018) and therefore offer limited capabilities for visualization, interpretation, and understanding of the complex datasets. Most of the current data of MES flow benefits are in the form of tables, lists and charts that may take much time to understand and obtain insights. As a first step toward communicating the information effectively, this research mapped the MES flow benefits across the globe using an interactive web mapping application to bring out valuable, possibly hidden insights to the end-users. Moreover, interactive web mapping of flows of benefits has yet to be implemented in MES or ES in general and herein we provide an initial approach in the domain of interactive web mapping. Better communicating the current baseline data is important in analysing and understanding the current situation and its drivers of change for decision making and scenario analysis and it also enables information that was previously not considered in fisheries management to be considered.

Branching origin-destination data is still an under-developed area in the field of cartography. Researchers suggest that more research needs to focus on the use of (carto-)graphic design principles and visual information thinking fundamentals in the implementation of these types of interactive cartographic products (Boyandin, 2013; Jenny et al., 2018). I, therefore, provided a method for mapping this type of data incorporating design principles discussed in the literature. Beyond the design principles, it has been suggested by several researchers that any cartographic product should be designed with a focus on the users to ensure that the information mapped by the cartographer closely matches the information retrieved by the user (Alkema et al., 2013; Roth et al., 2015). It has also been proven that having an early focus on understanding the users and their use context and carrying out an empirical evaluation with the users, results in the design of a product that sufficiently meets the user needs by increasing satisfaction and user-productivity (Baxter et al., 2015; Lorena, 2019; van Elzakker & Wealands, 2007)). For these reasons, the methodological framework of this research employed a User-Centred Design approach in the design and implementation of the application to create a product that satisfies the users' needs.

The main outcome of this research is an interactive web mapping prototype that demonstrates a proof concept of visualizing such flows based on design principles and general conventions. The overall approach to this research is centred on a UCD process. The methodology entailed step by step processes based on the research objectives. In the first objective, we used information-gathering method to determine the users and user requirements synthesised from literature. After which we derived data from reports and datasheets for the chosen case of WCPO tuna fish purse seine fishery. We then defined a data inclusion criterion and used this in determining the relevant data and indicators that would be mapped. In the second objective, we used the outcomes of the first objective and a scenario-based design method to create case scenarios that would inform the functional requirements for implementation. Based on visual design principles, general convention, and (carto-)graphic design principles we produced conceptual designs. These designs were then used in the third objective where we implemented the prototype based on a prototypical workflow for full-stack development. The final step addressing the fourth objective entailed a two-step iterative usability testing with selected test participants to provide recommendations for adaptations of the final prototype implementation.

The interactive visualization that I created in this research visualizes data for tuna fish caught by purse seeing fishing gear for the year 2013, in some cases due to missing data and ambiguity this data may have been altered for prototype demonstration or presented as missing or no data in the visuals. The aim was to have the ability to visualize the several steps in the supply value chain, the spatial interactions that exist, and the distributions per segment. In hindsight, the data used for this case study could be applied to a different global supply chain or distant ES flows. In this research, the case chosen was primarily to demonstrate the proof of concept. The usability testing resulted in a very useful and important critique by uncovering of usability issues for improving the application. Nonetheless, there was also a lot of positive feedback from test participants who believe the application met most of their needs. It was concluded from the testing that the application had a success rate in achieving the correct task of 86% based on the tasks questions set i.e. all users could use the application to achieve the executable tasks correctly where occasionally only failed to achieve one task. The prototype was also reviewed by the chosen project expert in the second round of testing where the results showed that the application proved to be sufficiently useful in addressing the users' needs. In retrospect, the outcomes of the empirical evaluations sufficiently determined that the application was quite useful for the set goals and objectives. The test participants also commented on areas they believe the application could be reproducible based on their expertise. The implementation of this application was successfully guided by objectives and resulting research questions which are answered below.

5.1.1. Research Questions answered

This research addressed the challenges presented with the main objective; "To develop and test with selected end-users an interactive web mapping application to visualize the flow of marine ecosystem services from the service supplying are to the service benefiting area across the globe. We were guided by the following sub-objectives:

1. To analyse formerly defined user requirements and delineate as well as systematically organize the set of suitable indicator data for mapping of MES flows in the WCPO region.
2. To design an interactive web mapping application for the visualization of marine ES flows.
3. To build and implement an interactive web mapping prototype to facilitate visualization of marine ES flows.
4. To test the usability of the prototype application with selected end-users.

Research questions were developed to guide the step by step process of addressing these objectives. The answers to the research questions are explained below:

RQ 1: To analyse formerly defined user requirements and delineate as well as systematically organize the set of suitable indicator data for mapping of MES flows in the WCPO region.

i. Which are the requirements by the end-users for the system based on analysis of user research to communicate marine ES flows for the selected case?

This research question is answered using information gathering methodology where a thorough literature review of previous documentation was carried out primarily focusing on Rühringer, (2018)'s work. The results and work presented in literature were synthesised and summarized in the results (section 4.1) where we presented the identified users, their requirements and needs, the user's goals and purposes and mapping recommendations based on these users. The answer to this question has been briefly summarized in Table 18 section 4.1.2.

i. Which is the relevant ES indicator data and in what way shall this be organised based on user requirements in preparation for data storage and distribution?

The first part of this question is related to the data that is obtained and what observations or values are relevant to map MES services. The answer to this question is based on an analysis of the chosen case study presented in methodology as well as the use of a data inclusion criteria methodology created to determine what is the most relevant and suitable indicator data for mapping MES (Table 9, section 3.5.3). Based on these criteria and the case study review I highlight the chosen indicators or observations as weight in metric tons and dollar value of fish caught by resource owners (i.e. fish-origin catch), weight in metric tons and dollar value of fish caught by fleet owners (catch by national fleet), weight in metric tons and %share of fish processed by a region (fish processing and export) and the related markets as a percentage of exported tuna from processing locations as summarized in Table 8 section 3.5.2.

The latter part of the question refers to the organization and preparation of data for storage and distribution which has been described in the results section. We explain the step by step process from acquiring the data, cleaning, and pre-processing it, then we use python scripting to push the data to a PostgreSQL database. From the database spatial queries are performed and python scripting is again used to restructure and write the final dataset to the correct file format. The steps involved in each stage of data preparation and organisation, storage, and distribution are discussed in section 4.3.1 and 4.3.2 final data structure prepared for distribution is presented in Figure 48 and Figure 49.

RQ 2: To design an interactive web mapping application for the visualization of marine ES flows.

i. Which technologies are needed to design an interactive web mapping application for marine fish trade flows?

The choice of technology of designing an interactive web mapping application is important to ensure ease of quick adaptations and feedback from experts. As discussed in the methodology the design process entailed the creation of both low and high-fidelity prototypes. Technologies, therefore, entailed paper sketching and MockFlow online application for low fidelity prototyping of the web app layout and AdobeXD for high fidelity prototyping of the web app layout and map composition and the User Experience interactive design. The outcomes of using these technologies are presented in the figures in section 4.2 and the UX design by AdobeXD can be accessed via a shared online resource (https://bit.ly/2MtXqBd).

ii. What are the steps required in designing of the application?

The approach for designing the interactive web application is provided in section 3.6 on the methodology of the conceptual design. It entailed 3 steps data design and functional requirements, representation design of web map layout and web map composition, and then the interaction design. The outcomes of each step are presented in the results. The steps encompass the following:

- Data design and functional requirements use the scenario-based approach which entailed creating use case scenarios (Table 21 and Table 22) where we derive the goals and tasks which then inform the application's functional requirements. The methods or steps are described in section 3.6.1 and the results presented in Table 23 (section 4.2.1).
- Representation design is the next step where the functional requirements are then used to conceptualize the ideas. This stage entails designing the User Interface web map layout and

components. It includes two sub-steps creating low-fidelity prototypes then high-fidelity prototypes of the web map layout and web map composition as described in section 3.6.2. The outcomes of this step are presented in section 4.2.2.

- Interactivity design is the final step in designing of the application where the user experience is considered. The methodology discussed in section 3.6.3 entailed considering possible common interaction techniques and operator-based primitives. The outputs of interaction are described where Shneiderman's visual information seeking mantra is used as a guiding principle in section 4.2.3.

iii. Which scientific guidelines and principles will be used in determining suitable geo-visualization approaches and cartographic designs based on the chosen set of indicator data for the end-user requirements?

This research focused on the creation of the interactive web mapping application based on guiding principles and general conventions to ensure that it sufficiently addressees the end-user needs and requirements. For this purpose, a thorough review of the literature was carried out to determine the most relevant guiding principles in the conceptual design. The principles used and their description of how they were implemented in the design of the application are presented in Table 25 (section 4.2.4). The main principles considered in the general web application layout include:

- Principles of visual design by Lovett (1999)
- Norman, (1988)'s 7 fundamental design rules.
- Shneiderman's 8 golden rules by Shneiderman and Plaisant (2010)
- Shneiderman, (1996)'s visual information seeking mantra and type by task analysis for task identification (TTT)

The chosen cartographic design principles are based on:

- Flow Mapping principles for OD data representation of direction, magnitude, self-loops, and bidirectionality (section 2.2.4).
- Cartographic design principles described in Table 3 section 2.2.3 (Turchenko, 2018).
- Cartographic map recommendations provided by Rühringer, (2018) discussed in Table 19 and Table 20 (section 4.1.3)
- The cartographic visual variables used in determining the visual representation of the data Figure 10 (section 2.2.3)

RQ 3: To build and implement an interactive web mapping prototype to facilitate visualization of marine ES flows.

i. What are the desired functionalities and capabilities of the prototype by the end-users?

The functionalities or application requirements are derived from the use and user requirements and scenario-based design methodologies. The answer to this question is presented in the form of functional requirements to be implemented in the design space (Table 23) section 4.2.1 were the derived requirements are used in the conceptual design of what should be implemented. Furthermore, I structured these outcomes to implement the web prototype in the solution space using a functional relational framework for the website implementation as shown in Figure 50 (section 4.3.3).

ii. What technologies and infrastructure are needed for building and implementing the prototype?

The technologies and justification for choosing these technologies are mainly presented in the methods section 3.7.1. I explained the prototypical workflow for the implementation, the technologies, and the reasons for using these technologies. The use of each of these technologies are described in the step by step procedure of system implementation (section 4.3) and they include:

- Python scripting for data curation and manipulation, data ingestion into the database, and reformatting.
- PostgreSQL and PgAdmin for manipulating the data, performing spatial queries, and joins of the data.
- HTML, CSS, and JavaScript and JS libraries such as jQuery, bootstrap, popper for user interface design and implementation.
- D3.js library and SVG for creating the visualization elements, binding data to these visualizations, and providing interactivity functionalities.
- Git and GitHub for code versioning, storage, and sharing of the codebase.
- PyCharm and WebStorm Integrated Development Environments (IDE's) which were the main code editors for development

iii. What are the potential challenges or limitations in the design and implementation of the system?

The challenges encountered and limitations to the implementation of the system are derived from the results of implementation (section 4.3) and user testing (section 4.4 and 4.5). The answer to this question is further elaborated in the limitations section (5.2). Major challenges expected focused on data and technical capabilities in achieving the desired design concepts. Another limitation was that the data was unique and contained incomplete information, however, to address this an inclusion criteria methodology was used to obtain data that would be relevant for proof of concept. Another challenge that had been anticipated was with the technical knowledge of using D3.js. D3 is a very powerful JavaScript library that allows for very robust customization; nevertheless, it has a steep learning curve and requires much time to explore most of its capabilities. In that regard, some customization features described in the design concept were not implemented due to technical skills which are also elaborated further in limitations.

RQ 4: To test the usability of the prototype application with selected end-users.

i. Which set of executable tasks will be required to assess the application's usability for the end-user?

An empirical evaluation was carried out to test the usability of the application. The method in identifying the executable tasks for usability testing entailed hypothesis formulation then based on these goals and task identification method, we formulated executable tasks centred on the level of difficulty in formulating geographic questions (van Elzakker, 2004). The answers to this research question are summarized in Table 16 (section 3.8.2). The sample questions are used in the empirical evaluation as the executable sub-tasks based on specific geographic questions related to their difficulty level and the main tasks they seek to address. These are then categorized under the measure of usability i.e. effectiveness, efficiency, and satisfaction.

ii. What are the potential limitations and recommendations for the improvement of the prototype for the end-user?

The answer to this question is in sections 4.4 and 4.5 which provides an analysis of the results of the usability testing. The usability testing resulted in identifying issues or limitations in the prototype and receiving recommendations or suggestions from test participants. The recommendations for improvements and the limitations are provided in a summarised form in Table 32 and Table 33 where we describe the comments/suggestions from test participants and provide solutions for adaptations to improve the prototype. We also indicate whether the adaptation was implemented or not and discuss the reasons and limitations of not implementing some suggestions. After adaptations, a second formative testing was conducted with the expert user to provide recommendations on satisfaction and feedback for future use of the application. These are presented in Table 35.

iii. What are the boundary conditions under which the application may be applied in other areas for future work?

The boundary conditions are derived from the design and implementation strategies as well as the suggestions from the usability testing results. Some pre-requisite to reproduce this system in other areas include:

- The data structure and data type.
- Availability of complete information on spatial relationships.
- Availability of spatial information either directly derived or implied e.g. geographic names or codes.
- The size of data may be a limiting factor in the presented design due to visual clutter.

When considering the conditions of reproducing this application the size of the data also matters. A dataset's size can be determined based on storage amounts e.g. 1 GB of data or the microdata (information on individual components). This research mapped a few individual relationships (less than 50). However, the more the relationships the more the flow lines. Large data sets, possibly an excess of 200 flows requires rethinking. Ideally, large datasets should also be possible to be mapped however additional interactive design approaches should be considered in this case. Some alternatives are described in the literature review section 2.2.4 under the challenges of flow maps. Researchers such as Boyandin, (2013) and Jenny et al., (2018) further illustrates design strategies to address these challenges. Other researchers propose a statistical approach to defining a threshold to obtain the most representative sample of data (Maleki, 2016).

The data type or structure should follow the characteristic general features of OD data (section 3.5.2). This implies that comparable application areas such as global value supply chains of products could be reproduced in a similar approach to create interactive web visualizations. Another data type that contains similar characteristics is the flows of other Ecosystem Services beyond Marine Ecosystem Services, whose benefits are realized beyond the spatial bounds of the supplying area or where flows are spatially distant e.g. provision of food and raw materials such as timber, coffee, etc., where the flows delineate the process of storage, commercial trade and demand (Serna-Chavez et al., 2014; Syrbe & Walz, 2012). From the outcomes of the second round of usability testing another area where visualization of flows of benefits could be crucial is in showing the different sectors of the blue economy such as tourism, fisheries, transport, etc., for a given region or country in the Exclusive Economic Zones (EEZ). If data permits and based on feasibility of the amount of work this could also be extended to visualize a global map of tuna fish flows where other tuna fisheries are incorporated. The methodology thus provided in this research from the choice of data and inclusion, structuring of data, design and implementation of the prototype can be adapted to these other application areas depending on data constraints and feasibility of the project.

5.2. Limitations

The implementation of any interactive web mapping application presents various technical and theoretical challenges. Most of those encountered in the process of design and implementation were due to technical capabilities and they include:

1. Errors in interpretation of the Sankey diagram. Due to the limited technical skills of implementing the design, the placement of nodes in the Sankey diagram led to confusion and resulted in errors.

Ideally, the design was to create an alluvial Sankey diagram where the positions of the nodes are based on the attribute of the beneficiary to mean that the first position would refer to the harvest (fleet/resource) then the process and the last position would be the market. This was technically difficult to implement since we could not visualize repeated nodes as explained in the results and discussions. Hence node placement was mainly based on origins and destinations regardless of their role in the beneficiary supply chain. Nevertheless, the Sankey had been included to determine the names of these beneficiary types despite the different spatial resolution.

2. Another limitation was in the use of colours in the Sankey diagram which could result in wrong perceived meaning. Based on Miller's Law (Yablonski, n.d.), the human mind can only cognitively discern 7 (plus or minus 2) items. Therefore, we theorized that all visual representations should use 6-8 colours. Taking this into consideration it means that for the Sankey diagram some of the nodes would be represented with similar colours. However, this does not have any significant meaning in the visualization, but we do realize that it may result in errors by the user. A choice had to be made between visual overload, choice of colour combinations for colour blindness, and having unique colours for each node. We decided visual overload and colour blindness were the most important.
3. The flow map posed a challenge or limitation in the design and implementation of self-loops (one-to-one loops) that exist at different stages of the supply chain. The challenge here was the overlap or occlusion of flows in the case of one-to-one interactions e.g. Japan has one-to-one interactions at two steps in the supply chain, a resource to processing and processing to market. This means that one flow loop will show above the other. The alternative solution provided was filtering using the legend to allow users to visualize only flows of the supply chain step they are interested in. Still, we believe that there could be a better design and implementation strategy to reduce user's fatigue which could be explored in future research.
4. Another limitation in the flow map is the representation of the Small Island Developing States (SIDS). Based on the outcomes of the usability testing, a recommendation was to provide zooming to feature and/or highlight when a country is searched in the search panel. Ideally, this would help to view the small island countries. This functionality was implemented in the adapted final prototype however it had some technical hitches where the zooming transition was not a smooth transition and resetting to the entire map extent or reversing the action was another challenge to implement. Hence the zooming implementation was removed since it added more work to the users when they needed to view the entire globe. Consequently, we choose to only use highlight to identify searched features that still did not solve the issue. Another interactivity considered for small island countries was using magnification or inset maps to zoom on these countries, however with time and technical limitations these functions were not fully explored for implementation.
5. Data used for prototype demonstration was another limitation in the implementation due to data inconsistencies and incompleteness. It involved a lot of pre-processing and cleaning, and quite some data had to be eliminated due to a lack of spatial relationships. This, therefore, means that the representation may not be a holistic depiction of reality. However, this was merely for prototype demonstration and is suggested that for future implementation data inclusion criteria and constraints suggested in the methodology should be used. Additionally, the data visualized was percentage share distributions which were the most available information, however, this expended more time resource to interpret and understand the information as seen in the usability testing outcomes. It was difficult for some users to derive the meanings without further explanation.
6. Despite producing a prototype that met most of the conceptual design requirements, some technical limitations hindered the implementation of different spatial resolution views. We were not able to provide this at different spatial aggregation levels due to technical limitations and design

considerations. It was also argued that aggregating flows to continental level would lose the meaning or purpose of the interactive web map which is to visualize the beneficiaries and their flows, aggregation would hence result in five continents and bring the ambiguous interpretation of flows thus only one spatial resolution, country level, was implemented.

7. The application utilizes a file-based system which is not the ideal situation in interactive web mapping. Nevertheless, this was chosen because the project was a small-sized project. The limitation is that the web application is not future proof for the expansion in data which should be considered in future work.
8. Ideally, the application should have been designed and implemented with principles of responsive web design or mobile-first approach, however, there were a few mostly technical challenges encountered when implementing this and therefore we opted to offer a desktop-friendly version and suggest that future implementation contemplate responsivity. The downside to not considering responsive web design is that due to different screen sizes, some users may have trouble viewing the entire content and some positional styling may be lost in different browsers. It was realized that the most appropriate browser that supports all the CSS styling implemented was Google Chrome.

5.3. Suggestions for Design and Implementation

The prototype implementation is based on a thorough review of design concepts. For reproducibility and future implementation of an interactive web application, it is important to apply the boundary conditions mentioned. Below are recommendations that could be applied by designers and developers:

1. Data type: the flow map design is based on using a dataset which is a unique type of OD data. To reproduce the interactive web map, the type of data should contain the following characteristics:
    - Spatial links /relationships (description of the movement of quantity from one location to another location)
    - Spatial locations of the start(origin) and end (destinations) nodes.
    - Characteristics of the step in the value chain e.g. from harvest to process, from process to market
    - The magnitude of movement of the observed quantity e.g. metric tons, dollar value etc.
2. Flow mapping design should consider the factors such as the representation of direction, magnitude, bi-directionality, self-loops, and origins and destinations. The chosen designs should avoid clutter and occlusion. Strategies to prevent visual clutter using interactivity should be used (Boyandin, 2013; Jenny et al., 2018).
3. To enable reproducibility of this application for other global value supply chains the structure of the final dataset should be structured to enable using D3 libraries for mapping depending on the chosen visuals. Figure 48 and Figure 49 show examples of the final data structures used for flow map, Sankey diagram, and stacked bar chart.
4. Colour choice is also of importance in design consideration. Based on guidelines and recommendations by Rühringer, (2018) various colour combinations should be distinguishable for variations of colour-blindness. The colour scheme should match the structure of the data and avoid visual overload.
5. Larger projects that entail large amounts of data, should incorporate design strategies that minimize clutter. The developer should also use distributed services that read data from database storage over a file-based storage system as this would allow for robustness and future expansion of datasets in the application.

5.4. Recommendations for Future Work

This research outlined some limitations and suggestions for adaptation in reproducing an interactive web map prototype. Here I further provide areas of research and recommendations for future work:

- Further investigation may be carried out to determine the feasibility of adopting these methods, guidelines, and design principles to other areas such as those mentioned in the boundary conditions. These areas may include visualization of other types of global supply value chains, visualization of the relationships that occur in other types of ecosystem service flows, capturing the flows of benefits of other tuna fisheries as a global map perspective or the visualization of flows of economic benefits for different sectors of the blue economy for a given region to inform marine policy and blue economy strategies. These may be explored as an approach to better communicate the information presented in the different areas.
- The data visualized was mainly percentage share distributions due to missing information. This took slightly more time and explanation for users to understand the meaning of the data. Ideally, it would be preferred to use actual observed values for the choropleth maps, stacked bar chart and the flow path magnitude. This would enable users to discern or interpret the information much more efficiently and accurately. Hence future application areas should acquire the actual observational values if the data permits. As suggested by test users in the usability testing from a marine policy perspective the next steps would be to visualize the actual economic values such as percentage of access fees for resource and percentage of the delivered value of catch for the fleet owners and to allow for comparison of the two to see how significant volumes of catch is from foreign fleets in the waters of resource owners against what the resource owners catch.
- The research demonstrates the visualization of small datasets and therefore the chosen implementation strategy is suitable. Nevertheless, for large datasets, further research is required to determine an alternative approach to sampling the data such as statistical sampling or alternative design methods to avoid clutter. Furthermore, the implementation strategy should cater to a robust system such as using the approach of having distributed services from a web map server that reads directly from a database.
- Rühringer, (2018) mentions that though interactive maps exist most of these have limited functions and capabilities. Here we introduced interactivity such as filter, search, zoom, linking, and dynamic queries. However, further investigation can be done on the use of various operator-based primitives for interactivity and how they can be implemented to enable functions such as smooth panning, magnifying on small island countries, or providing inset or location maps to tackle the issue of Small Island Developing States (SIDS).
- Future adaptations could also provide extensive investigation on flow map design and design of branching OD data to provide alternative workarounds with regards to one-to-one interactions (self-loops)that have the same origin and location for different steps in the supply chain. An alternative design to using filters could be implemented to avert the issue of obscuring flow lines.
- Further research on the technical implementation of the Sankey diagram can be done to enable customization of node placement. This would bring meaning to the positions of the nodes that are crucial in the interpretation of the visualization.
- Finally, research can be conducted on the methods and principles of responsive web design and the prototype should be implemented with a mobile-first approach to ensure usability by a wider audience with different screen sizes.

LIST OF REFERENCES

Alkema, D., Bijker, W., Sharif, A., Vekerdy, Z., & Verhoef, W. (2013). *The Core of GIScience a systems based approach*. (V. Tolpekin & A. Stein, Eds.), *Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente*. Enschede: Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente.

Andrienko, N., Andrienko, G., & Gatalsky, P. (2003). Journal of Visual Languages & Computing Exploratory spatio-temporal visualization: an analytical review ARTICLE IN PRESS. *Journal of Visual Languages and Computing*, *14*, 503–541. https://doi.org/10.1016/S1045-926X(03)00046-6

Bahoken, F. (2011). Représentation graphique des matrices. Graphe et/ou carte des flux? 2011. halshs-00641733

Baldonado, M. Q. W., Woodruff, A., & Kuchinsky, A. (2000). Guidelines for Using Multiple Views in Information Visualization. *Proceedings of the Workshop on Advanced Visual Interfaces*, 110–119. https://doi.org/10.1145/345513.345271

Baxter, K., Courage, C., & Caine, K. (2015). Introduction to User Experience. *Understanding Your Users*, 2–20. https://doi.org/10.1016/b978-0-12-800232-2.00001-8

Bertin, J. (1967), Sémiologie graphique. Les diagrammes, les réseaux, les cartes. Paris - La Haye / Paris: Mouton / Gauthier-Villars.

Bertin, J. (1983). Semiology of graphics. Diagrams, networks, maps. Madison: The University of Wisconsin Press. Retrieved from http://catalogue.nla.gov.au/Record/2340325

Bevan, N., Carter, J., Earthy, J., Geis, T., & Harker, S. (2016). New ISO standards for usability, usability reports and usability measures. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* (Vol. 9731, pp. 268–278). Springer Verlag. https://doi.org/10.1007/978-3-319-39510-4_25

Bostock, M., Ogievetsky, V., & Heer, J. (2011). D³ Data-Driven Documents. *IEEE Transactions on Visualization and Computer Graphics*, *17*(12), 2301–2309. https://doi.org/10.1109/TVCG.2011.185

Bowman, D., Gabbard, J. L., & Hix, D. (2002). *A Survey of Usability Evaluation in Virtual Environments: Classification and Comparison of Methods. A Survey of Usability Evaluation in Virtual Environments: Classification and Comparison of Methods*. *Presence: Teleoperators and Virtual Environments* (Vol. 11).

Boyandin, I. (2013). *VISUALIZATION OF TEMPORAL ORIGIN-DESTINATION DATA*. University of Fribourg. Retrieved from https://ilya.boyandin.me/assets/thesis.pdf

Boyandin, I., Bertini, E., Bak, P., & Lalanne, D. (2011). Flowstrates: An Approach for Visual Exploration of Temporal Origin-Destination Data. *Computer Graphics Forum*, *30*(3), 971–980. https://doi.org/10.1111/j.1467-8659.2011.01946.x

Brewer, C. A. (2016). Designing better maps: a guide for GIS users (2nd ed.). Esri Press.

Burkhard, B., & Maes, J. (Eds.). (2017). *Mapping Ecosystem Services. Methods*. Bulgaria: Pensoft Publisher. https://doi.org/10.1097/00000433-198206000-00020

Butz, A. (n.d.). *LMU München-Medieninformatik-Informationsvisualisierung-WS2011/12*. Retrieved from http://www.hiraeth.com/alan/topics/vis/hist.html

Daw, T. M., Hicks, C. C., Brown, K., Chaigneau, T., Januchowski-Hartley, F. A., Cheung, W. W. L., … McClanahan, T. R. (2016). Elasticity in ecosystem services: exploring the variable relationship between ecosystems and human well-being. *Ecology and Society*, *21*(2), art11. https://doi.org/10.5751/ES-08173-210211

Debiasi, A., Simões, B., & De Amicis, R. (2014). Force Directed Flow Map Layout. In *Proceedings of the 5th International Conference on Information Visualization Theory and Applications* (pp. 170–177). SCITEPRESS - Science and Technology Publications. https://doi.org/10.5220/0004744601700177

Delikostidis, I. (2011). *IMPROVING THE USABILITY OF PEDESTRIAN NAVIGATION SYSTEMS*.

DiBiase, D. Visualization in the earth sciences. Bulletin of the College of Earth and Mineral Sciences 59, 2 (1990), 13–18.

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., … Zlatanova, D. (2015). *The IPBES Conceptual Framework - connecting nature and people*. *Current Opinion in Environmental Sustainability* (Vol. 14). Elsevier. https://doi.org/10.1016/j.cosust.2014.11.002

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R. T., Molnár, Z., … Shirayama, Y. (2018). Assessing nature's contributions to people. *Science*, *359*(6373), 270–272.

https://doi.org/10.1126/science.aap8826
Donohue, R. G. (2014). *Web Cartography with Web Standards: Teaching, Learning, and Using Open Source Web Mapping Technologies*. WISCONSIN-MADISON. Retrieved from https://geography.wisc.edu/cartography/people/StudentTheses/Donohue_2014_WebCartographyWithWebStandards.pdf
Drakou, E. G., Crossman, N. D., Willemen, L., Burkhard, B., Palomo, I., Maes, J., & Peedell, S. (2015). A visualization and data-sharing tool for ecosystem service maps: Lessons learnt, challenges and the way forward. *Ecosystem Services*, *13*, 134–140. https://doi.org/10.1016/J.ECOSER.2014.12.002
Drakou, E. G., Kermagoret, C., Liquete, C., Ruiz-Frau, A., Burkhard, K., Lillebø, A. I., … Peev, P. (2017). Marine and coastal ecosystem services on the science-policy-practice nexus: Challenges and opportunities from 11 European case studies. *International Journal of Biodiversity Science, Ecosystem Services and Management*, *13*(3), 51–67. https://doi.org/10.1080/21513732.2017.1417330
Drakou, E. G., Pendleton, L., Effron, M., Ingram, J. C., & Teneva, L. (2017). When ecosystems and their services are not co-located: Oceans and coasts. *ICES Journal of Marine Science*, *74*(6), 1531–1539. https://doi.org/10.1093/icesjms/fsx026
Drakou, E. G., Virdin, J., & Pendleton, L. (2018). Mapping the global distribution of locally-generated marine ecosystem services: The case of the West and Central Pacific Ocean tuna fisheries. *Ecosystem Services*, *31*, 278–288. https://doi.org/10.1016/J.ECOSER.2018.05.008
Dunnewind, M., Gupta, P., van Schooten, S., & van der Veeken, P. (2016). D3.js · Delft Students on Software Architecture: DESOSA 2016. Retrieved May 26, 2020, from https://delftswa.gitbooks.io/desosa2016/content/d3js/chapter.html
FFA. (2016). FFA Economic and Development Indicators and Statistics 2016 | Pacific Islands Forum Fisheries Agency (FFA). Retrieved May 5, 2020, from https://www.ffa.int/node/1877
Fisher, B., Christie, M., Aronson, J., Braat, L., Gowdy, J., Haines-Young, R., … Shmelev, S. (2010). *Chapter 1 Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation*.
Garrett, J. J. (2000). The Elements of User Experience. Retrieved March 22, 2020, from http://uxdesign.com/assets/Elements-of-User-Experience.pdf
Garrett, J. J. (2002). *The Elements of User Experiences: User-Centered Design for the Web*. New York.
Geoconnections. (2007). Understanding users' needs and user-centered design, 1–68.
Haines-Young, R., & Potschin, M. (2013). *Common International Classification of Ecosystem Services (CICES): Consultation on Version 4*. Nottingham. Retrieved from https://cices.eu/content/uploads/sites/8/2012/07/CICES-V43_Revised-Final_Report_29012013.pdf
Häyhä, T., Franzese, P. P., Paletto, A., & Fath, B. D. (2015). Assessing, valuing, and mapping ecosystem services in Alpine forests. Ecosystem Services, 14, 12–23. https://doi.org/10.1016/j.ecoser.2015.03.001
Haklay, M. (2010). *Interacting with geospatial technologies*. John Wiley.
Haklay, M., & Tobón, C. (2003). Usability evaluation and PPGIS: Towards a user-centred design approach. *International Journal of Geographical Information Science*, *17*(6), 577–592. https://doi.org/10.1080/1365881031000114107
Hamilton, A., Lewis, A., McCoy, M. A. M., Havice, E., & Campling, I. L. (2011). *Market and industry dynamics in the global tuna supply chain. Forum Fisheries Agency, …*. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Market+and+industry+dynamics+in+the+global+tuna+supply+chain#0
Interaction Design Foundation. (n.d.-a). What are Affordances? | Interaction Design Foundation. Retrieved May 18, 2020, from https://www.interaction-design.org/literature/topics/affordances
Interaction Design Foundation. (n.d.-b). What is Information Visualization? | Interaction Design Foundation. Retrieved May 18, 2020, from https://www.interaction-design.org/literature/topics/information-visualization
Interaction Design Foundation. (n.d.-c). What is User Interface (UI) Design? | Interaction Design Foundation. Retrieved May 18, 2020, from https://www.interaction-design.org/literature/topics/ui-design
ISO. (1986). ISO - ISO 8402:1986 - Quality — Vocabulary. Retrieved March 3, 2020, from https://www.iso.org/standard/15570.html
ISO. (1999). ISO 13407:1999(en), Human-centred design processes for interactive systems. Retrieved March 2, 2020, from https://www.iso.org/obp/ui/#iso:std:iso:13407:ed-1:v1:en
Jenny, B., Stephen, D. M., Muehlenhaus, I., Marston, B. E., Sharma, R., Zhang, E., & Jenny, H. (2017).

Force-directed layout of origin-destination flow maps. *International Journal of Geographical Information Science*, *31*(8), 1521–1540. https://doi.org/10.1080/13658816.2017.1307378
Jenny, B., Stephen, D. M., Muehlenhaus, I., Marston, B. E., Sharma, R., Zhang, E., & Jenny, H. (2018). Design principles for origin-destination flow maps. *Cartography and Geographic Information Science*, *45*(1), 62–75. https://doi.org/10.1080/15230406.2016.1262280
Jp, L.-L. C., & Oppong, S. H. (2013). Asian Journal of Management Sciences and Education The Problem of Sampling in Qualitative Research. Retrieved from www.ajmse.leena-luna.co.jp
Kahneman, D., & Tversky, A. (1972). Subjective probability: A judgment of representativeness. *Cognitive Psychology*, *3*(3), 430–454. https://doi.org/10.1016/0010-0285(72)90016-3
Kaye, N. R., Hartley, A., & Hemming, D. (2012). Mapping the climate: guidance on appropriate techniques to map climate variables and their uncertainty. Geoscientific Model Development, 5(1), 245– 256. https://doi.org/10.5194/gmd-5-245-2012
Kraak, M.-J., & Ferjan, O. (2010). *Cartography: Visualization of Spatial Data* (Third). New York: Routledge.
Liquete, C., Piroddi, C., Drakou, E. G., Gurney, L., Katsanevakis, S., Charef, A., & Egoh, B. (2013). Current Status and Future Prospects for the Assessment of Marine and Coastal Ecosystem Services: A Systematic Review. *PLoS ONE*, *8*(7), e67737. https://doi.org/10.1371/journal.pone.0067737
Lorena, V. (2019). Use and User-Centred Design of Ecosystem Services Maps. Retrieved from https://library.itc.utwente.nl/login/2019/msc/gfm/gutierrez.pdf
Lovett, J. (1999). Design Overview | John Lovett Design. Retrieved March 22, 2020, from https://www.johnlovett.com/design-overview
Maguire, M., & Bevan, N. (2002). User Requirements Analysis (pp. 133–148). Springer, Boston, MA. https://doi.org/10.1007/978-0-387-35610-5_9
Maleki, M. (2016). *Visualization of Trends in Od Matrix Data Illustrated By United Nations Refugee Data*. University of Twente. Retrieved from https://ezproxy.utwente.nl:2315/library/2016/msc/gfm/maleki.pdf
Millennium Ecosystem Assessment. (2005). *Ecosystems and Their Services: A Framework for Assessment*. Washington. Retrieved from https://www.millenniumassessment.org/documents/document.300.aspx.pdf
Morville, P. (2004, June 21). User Experience Design. Retrieved February 27, 2020, from https://semanticstudios.com/user_experience_design/
Muehlenhaus, I. (2013). The design and composition of persuasive maps. *Cartography and Geographic Information Science*, *40*(5), 401–414. https://doi.org/10.1080/15230406.2013.783450
Musso, F., & Druica, E. (2019). *Handbook of Research on Retailing Techniques for Optimal Consumer Engageent and Experiences*. (F. Musso & E. Druica, Eds.). United States: IGI Global. https://doi.org/10.4018/978-1-7998-1412-2
Nielsen, J. (1992). The Usability Engineering Life Cycle. *Computer*, *25*(3), 12–22. https://doi.org/10.1109/2.121503
Nielsen, J. (1993). *Usability engineering*. Academic Press.
Nielsen, J., & Mack, R. L. (1994). *Usability inspection methods*. New York : Wiley.
Norman, D.A., 1988. The design of everyday things, New York: Doubleday.
Palomo, I., Willemen, L., Drakou, E., Burkhard, B., Crossman, N., Bellamy, C., … Verweij, P. (2018). Practical solutions for bottlenecks in ecosystem services mapping. *One Ecosystem*, *3*. https://doi.org/10.3897/oneeco.3.e20713
Peterson, G. N. (2009). GIS cartography: a guide to effective map design (2nd ed.). Boca Raton: Taylor & Francis Group.
Potschin, M. P., Haines-young, R., & Jax, K. (2014). OpenNESS Glossary (V2.0). Retrieved from http://www.openness-project.eu/library/reference-book
Rhyne, T. M., MacEachren, A. M., Gahegan, M., Pike, W., Brewer, I., Cai, G., … Hardisty, F. (2004, January). Geovisualization for Knowledge Construction and Decision Support. *IEEE Computer Graphics and Applications*. NIH Public Access. https://doi.org/10.1109/MCG.2004.1255801
Robinson, A. C., Chen, J., Lengerich, E. J., Meyer, H. G., & MacEachren, A. M. (2005). Combining usability techniques to design geovisualization tools for epidemiology. *Cartography and Geographic Information Science*, *32*(4), 243–255. https://doi.org/10.1559/152304005775194700
Robinson, A. C., MacEachren, A. M., & Roth, R. E. (2011). Designing a web-based learning portal for geographic visualization and analysis in public health. *Health Informatics Journal*, *17*(3), 191–208. https://doi.org/10.1177/1460458211409718
Rosson, M. B., Carroll, J. M., Tech, V., & Va, B. (2002). *The Human-Computer Interaction Handbook:*

Fundamentals, Evolving Technologies and Emerging Applications. Lawrence Erlbaum Associates.
Roth, R. E. (2013). Interactive maps: What we know and what we need to know. *Journal of Spatial Information Science*, (6). https://doi.org/10.5311/JOSIS.2013.6.105
Roth, R. E. (2017). Visual Variables. In *International Encyclopedia of Geography: People, the Earth, Environment and Technology* (pp. 1–11). Oxford, UK: John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118786352.wbieg0761
Roth, R. E., Çöltekin, A., Delazari, L., Filho, H. F., Griffin, A., Hall, A., … van Elzakker, C. P. J. M. (2017). User studies in cartography: opportunities for empirical research on interactive maps and visualizations. *International Journal of Cartography*, *3*(sup1), 61–89. https://doi.org/10.1080/23729333.2017.1288534
Roth, R. E., Ross, K., & MacEachren, A. (2015). User-Centered Design for Interactive Maps: A Case Study in Crime Analysis. *ISPRS International Journal of Geo-Information*, *4*(1), 262–301. https://doi.org/10.3390/ijgi4010262
Ruckelshaus, M., McKenzie, E., Tallis, H., Guerry, A., Daily, G., Kareiva, P., … Bernhardt, J. (2015). Notes from the field: Lessons learned from using ecosystem service approaches to inform real-world decisions. *Ecological Economics*, *115*, 11–21. https://doi.org/10.1016/j.ecolecon.2013.07.009
Rühringer, M. (2018). *Use and User requirements of Ecosystem Service Maps Analyzing Decision Makers within the Use and User requirements of Ecosystem Service Maps*. University of Twente. Retrieved from https://cartographymaster.eu/wp-content/theses/2018_RUEHRINGER_Thesis.pdf
Serna-Chavez, H. M., Schulp, C. J. E., Van Bodegom, P. M., Bouten, W., Verburg, P. H., & Davidson, M. D. (2014). A quantitative framework for assessing spatial flows of ecosystem services. *Ecological Indicators*, *39*, 24–33. https://doi.org/10.1016/j.ecolind.2013.11.024
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). IEEE Comput. Soc. Press. https://doi.org/10.1109/VL.1996.545307
Shneiderman, Ben, and Catherine Plaisant. 2010. Designing the User Interface: Strategies for Effective Human-Computer Interaction. 5th ed. Boston: Addison-Wesley.
Slocum, T. A., Cliburn, D. C., Feddema, J. J., & Miller, J. R. (2003). Evaluating the usability of a tool for visualizing the uncertainty of the future global water balance. *Cartography and Geographic Information Science*, *30*(4), 299–317. https://doi.org/10.1559/152304003322606210
Smith, A. (2018). The Most Complete Design Thinking Tools & Resource Collections. Retrieved May 18, 2020, from https://medium.com/@soulless/the-most-complete-design-thinking-tools-resource-collections-675f40de36f6
Smith, M., Hillier, J. K., Otto, J.-C., & Geilhausen, M. (2013). Geovisualization. In S. J. F. (Ed.), *Reference Module in Materials Science and Materials Engineering* (Vol. 3, pp. 299–325). San Diego: Academic Press. https://doi.org/10.1080/01436590050004300
Stefaner, M. [2010]. Map your moves - A visual exploration of where New Yorkers moved in the last decade. Retrieved May 19, 2020, from http://moritz.stefaner.eu/projects/map%20your%20moves/
Syrbe, R. U., & Walz, U. (2012). Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics. *Ecological Indicators*, *21*, 80–88. https://doi.org/10.1016/j.ecolind.2012.02.013
Syrbe, R.-U., Schröter, M., Grunewald, K., Walz, U., & Burkhard, B. (2017). What to map? In B. Burkhard & J. Maes (Eds.), Mapping Ecosystem Services (1st ed., p. 374). Sofia: Pensoft Publishers. https://doi.org/https://doi.org/10.3897/ab.e12837
TEEB. (n.d.). TEEB - The Initiative. Retrieved May 19, 2020, from http://www.teebweb.org/about/the-initiative/
Tolochko, R. C. (2016). *Contemporary Professional Practices in Interactive Web Map Design*. University of Wisconsin - Madison. Retrieved from https://tolomaps.github.io/assets/Tolochko_Thesis.pdf
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 *Lecture Notes in Geoinformation and Cartography* (pp. 301–321). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-72029-4_20
Tufte, E. R. (1986). The visual display of quantitative information. Graphics Press, Cheshire, CT, USA. ISBN 0-9613921-0-X. (Cited
Turchenko, M. (2018). *Space-Time Cube Visualization in a Mixed Reality Environment New Approaches to Support Understanding Historical Landscape Changes*.
Tyner, Judith A. Introduction to thematic cartography. Englewood Cliffs, N.J.: Prentice Hall, 1992. "What

is a hologram? - Windows Mixed Reality." 2018. Retrieved May 17, 2020, from https://docs.microsoft.com/en- us/windows/mixed-reality/hologram

Tyner, J. A. (2010). *Principles of Map Design. Journal of Animal and Plant Sciences* (Vol. 53). https://doi.org/10.1017/CBO9781107415324.004

Usability.gov. (n.d.). Visual Design Basics | Usability.gov. Retrieved May 18, 2020, from https://www.usability.gov/what-and-why/visual-design.html

UX247. (2017). Formative and Summative Usability Testing - UX24/7. Retrieved June 2, 2020, from https://ux247.com/formative-summative-usability-testing/

UXmatters. (2012). UX Design Defined :: UXmatters. Retrieved May 18, 2020, from https://www.uxmatters.com/mt/archives/2012/06/ux-design-defined.php

van Elzakker, C. P. J. M. (2004). *The use of maps in the exploration of geographic data*. Utrecht University. https://doi.org/ISBN 90-6809-357-6

van Elzakker, C. P. J. M., & Wealands, K. (2007). Use and users of multimedia cartography. In *Multimedia Cartography: Second Edition* (pp. 487–504). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-36651-5_34

van Oort, P. (2006). *Spatial data quality: from description to application*.

Veenendaal, B., Brovelli, M. A., & Li, S. (2017). *Review of web mapping: Eras, trends and directions. ISPRS International Journal of Geo-Information* (Vol. 6). https://doi.org/10.3390/ijgi6100317

Wilke, C. O. (n.d.). *Fundamentals of Data Visualization*. O'Reilly Media. Retrieved from https://serialmentor.com/dataviz/color-basics.html

Williams, P., & Terawasi, P. (2015). *Overview of Tuna Fisheries in the Western and Central Pacific Ocean, including Economic Conditions. Paper prepared for the Eleventh Regular Session of the Scientific Committee; WCPFC* (Vol. 28). Pohnpei.

Wood, J., J. Dykes, and A. Slingsby [2010]. Visualisation of Origins, Destinations and Flows with OD Maps. Cartographic Journal, The, 47(2), pages 117–129. ISSN 00087041. doi:10.1179/000870410X12658023467367

World Bank. (2017). What is the Blue Economy? Retrieved June 1, 2020, from https://www.worldbank.org/en/news/infographic/2017/06/06/blue-economy

World Bank and Nicholas Institute. (2016). Tuna fisheries: Pacific possible background paper No 3, (3), 130.

Yablonski, J. (n.d.). Home | Laws of UX. Retrieved May 25, 2020, from https://lawsofux.com/

Ziv, G., Hassall, C., Bartkowski, B., Cord, A. F., Kaim, A., Kalamandeen, M., … Beckmann, M. (2018). A bird's eye view over ecosystem services in Natura 2000 sites across Europe. Ecosystem Services, 30, 287–298. https://doi.org/10.1016/j.ecoser.2017.08.011

APPENDIX A: USABILITY TEST QUESTIONNAIRE 1ST EVALUATION

Sample of the Usability Testing Questionnaire for the 1st Evaluation

Mapping of flows of benefits from marine ecosystems across the globe: Interactive Web Mapping Application

This survey seeks to assess the suitability in use of the created interactive web mapping visualizations for the chosen case of the fisheries from the Western Central Pacific Ocean (WCPO) Region.

Background

Using the case of the WCPO fisheries, better communicating the current baseline data is important in analysing and understanding the current situation and its drivers of change for decision making and scenario analysis and it also enables information that was previously not considered in fisheries management to be considered. The visualization provides an alternative communication tool of the baseline information to describe the global supply chain of these benefits across the globe. An interactive web mapping tool has therefore been created for this purpose and this survey tests the usability of the tool.

The aim of this survey is to test with potential users, alternative and possibly more efficiently ways of visualizing existing knowledge for improved management of fisheries flows. The ultimate goal of such an application is that it can be used for other global benefit flows beyond fisheries.

This survey entails 3 sections:

A. Tester's profile: This is a description of the user which you may fill. (approx. 5 min – can be completed before the session begins)

B. Effective and Efficiency Testing and Satisfaction User Testing: Consists of tasks that you will complete using the application created. (approx. 25 min)

C. Interview: Short interview session with the interviewer to get general feedback on additional comments. (should take max 15 min)

A. Tester's Profile

This section requires your information to assess the user's profile in relation to the application. Kindly fill in section below before the session begins.

1. My age group is:

   ☐ 18-25
   ☐ 25-35
   ☐ 35-50
   ☐ 50+

2. What is your highest completed education level?

   ☐ Bachelor
   ☐ Master
   ☐ Doctorate
   ☐ Other (please specify)

3. What is your educational background?

4. What is your main occupation? (profession/technical skills e.g. marine researcher)

5. Technical Expertise:

   i) Do you have any experience creating and/or using maps?

   ☐ No
   ☐ Yes, somehow - to small extent e.g. reading and interpreting static maps
   ☐ Yes, high level e.g. creating maps with GIS software such as ArcGIS, QGIS

   ii) If, yes do you have any familiarity with the use of web mapping applications/ interactive maps (e.g., Google Maps)?

   ☐ No
   ☐ Yes

   ii) Do you have knowledge on the use of a browser, and interactive map functions such as zoom, click etc?

   ☐ No
   ☐ Yes e.g. zoom and pan in google maps

6. Do you have any familiarity and/or have worked with the Western Central Pacific Ocean Pacific Possible Project?

   ☐ No
   ☐ Yes

   i) If yes, please specific in what capacity and work (e.g. I worked as an economic researcher for the project)?

B. Part 1: Visualization Effectiveness and Efficiency Testing

Scenario:

A project from World Bank would like to understand the benefits of tuna fish that are realized in different parts of the world. A visualization was requested by the management team to help understand these benefits. The visualization was created to illustrate:

- The type of benefits* realised i.e. resource (fish) owners, fleet owners and processing plants (The final market distribution has not been explicitly mapped; however, consumption destination is shown.)
- The distribution of these 3 benefits across the globe.
- The flows of these benefits from one location to the next.

*Benefit here refers to the economic value gained in terms of tuna fish weight in metric Tons and described as a % of the total catch weight per benefit type.

*Note: Some of the data such as destinations and percentage share may have been altered for purposes of prototype demonstration.

Tasks:

Look at the visuals carefully, read the title, descriptions on the sidebar and legend, try to understand all the information it contains before you start answering the questions. You may use the help and information tabs on the sidebar for assistance. In case you are completely stuck you may ask the interviewer. Use the visualization to achieve the tasks below.

The purpose is to measure the usability of the application and not your own ability in answering the questions. Kindly think aloud or talk loudly expressing what you are thinking as you try to achieve each task.

Section 1: Look at The Interactive Flow Map and Bar chart and answer the following questions

1. From the bar chart and flow map, what is the largest benefit type of Papua New Guinea with country code **PG**?

   ☐ Processing location
   ☐ Resource (fishery) owner
   ☐ Fleet owner
   ☐ None of the above

MAPPING FLOWS OF BENEFITS FROM MARINE ECOSYSTEMS ACROSS THE GLOBE

2. What is the weight in % share distribution of tuna fish caught by Micronesia with country code **FM** as a resource owner?

   ☐ 0%
   ☐ 0.7%
   ☐ 4%
   ☐ 11.4%

Section 2: Look at the Sankey diagram and flow map together and answer the following questions

3. What countries does Taiwan export tuna fish to for processing?

   ☐ Thailand
   ☐ Indonesia
   ☐ Thailand and China
   ☐ All the above

4. Based on the legend, the flow map and the Sankey, which regions do most countries export processed tuna to for consumption(market)? Pick the most suitable.

   ☐ EU and Middle East
   ☐ EU and United States
   ☐ United States and Asia
   ☐ All the above

Section 3: Switch between distribution maps i.e. resource, fleet and processing buttons to answer the questions below.

5. Which is the largest processing location of fish by weight in metric tons? (move mouse over countries to see values)

   ☐ Japan – 144410 mT
   ☐ Thailand – 591252 mT
   ☐ Indonesia – 215651 mT
   ☐ Thailand – 750,000 mT

MAPPING FLOWS OF BENEFITS FROM MARINE ECOSYSTEMS ACROSS THE GLOBE

6. Which country has the highest percentage of fleets fishing in WCPO?

   ☐ Thailand
   ☐ United States
   ☐ Papua New Guinea
   ☐ Japan

Section 4: Use the search pane on the side navigation or distribution maps to answer the following.

7. What is the main way that China benefits from tuna fish of the WCPO region?

   ☐ As a processing location
   ☐ As a market
   ☐ As a fleet owner
   ☐ All the above

Section 5: Using flow map only

8. Using the key/legend of the flow map name one country which processes tuna and consumes it domestically (processing to market). Hint: When start and end locations are the same flows are indicated by a closed circular loop. Choose most suitable.

   ☐ China
   ☐ Indonesia
   ☐ Japan
   ☐ USA

Part 2: Visualization Satisfaction Testing

9. Is the visualization misleading/ ambiguous e.g. does it convey confusing information? Kindly explain why.

   Poor ☐ ☐ ☐ ☐ ☐ Excellent

10. Is the choice of colours suitable? If no, please explain.

11. What is the best use for this visualization in your opinion?

    ☐ To have a general overview

    ☐ To answer specific details

    ☐ Both

    ☐ None of the above

12. How easy is it to use the visualizations?

    ☐ Simple and easy to use

    ☐ Moderately easy

    ☐ Difficult to use

    ☐ Very difficult to use

13. Kindly rate out of 1 to 5 how easy you found the following visualizations

    Flow Map -

    Bar chart -

    Sankey Diagram -

    Distribution Maps -

MAPPING FLOWS OF BENEFITS FROM MARINE ECOSYSTEMS ACROSS THE GLOBE

C. **Interview Section**

1. Do you have any suggestions for improvements?

2. Do you have additional comments, are all functions of the application useful and what could be removed?

APPENDIX B: FIRST USABILITY TESTING RESULTS

Test Participant Results

The following are the results of the user testing carried out between 7th May to 15th May 2020 to test the usability of the Marine Ecosystem Service Flows Interactive web app prototype. The aim was to test a minimum of 4 users with at least 1 project experts. 5 users out of 11 contacted users participated in the surveys and we had 2 project experts. The results below are given per user per and section. Part A retrieved the tester's profile, section B focused on the task analysis testing efficiency, effectiveness, and satisfaction and the last section was an interview discussion on general feedback. Section B part I was assessed based on the effectiveness and efficiency measures described in Table 27 (section 4.4.2).

User 1

Section A: Tester's Profile Results

User	Profile		Results
TP 1	Age group		35-50
	Highest Level of completed education		Doctorate
	Educational Background		Marine Policy
	Main occupation		Director of Ocean Policy Program, Nicholas Institute for Environmental Policy Solutions.
	Technical expertise	Experience using maps	No
		Familiarity with interactive maps and web applications	No
		Familiarity with interactive map functions	No
	Domain Knowledge	Are you familiar with Marine Ecosystem Service Flows?	Yes
	Use Case knowledge	Familiarity with the WCPO fisheries and the Pacific Possible Project reports?	Yes
		If involved in what capacity or work?	Researcher for a series of reports on Tuna fisheries.

Section B: Part I - Task Analysis Results Effectiveness and Efficiency

Questions	Time (sec)	Accuracy	Difficulty	Target Visual	Notes/comments
1. What is the largest benefit type of Papua New Guinea with country code PG?	10 – 50	Yes	Medium	Bar Chart	Mentioned that the naming of the axis is quite confusing. It does not understand what %share means.
2. What is the weight in % share distribution of tuna fish caught by Micronesia with country code FM as a resource owner?	0 – 10	Yes	Low	Bar Chart	The meaning of the values and why they stack up. Why use % share instead of actual values. Quite confusing.
3. What countries does Taiwan export tuna fish to for processing?	10 – 50	Yes	Medium	Flow map & Sankey	Direction using animation is appreciated to be quite effective
4. Which regions do most countries export processed tuna to for consumption (market)?	10 – 50	Yes	Low	Flow Map & Sankey	Mentioned that having Russia as the centroid of Europe is ambiguous and confusing as a domain expert. Suggests moving to the capital of the European Commission instead (Brussels).
5. Which is the largest processing location of fish by weight in metric tons?	0 – 10	Yes	Medium	Distribution maps	Confusion on the discrepancies of the data itself e.g. some countries have %share but 0 value in metric tons which is not logical. Suggests replacing 0 values with no data/ missing data.
6. Which country has the highest percentage of fleets fishing in WCPO?	10 – 50	Yes	Medium	Distribution maps	% share compared to metric tons not clear.
7. What is the main way that China benefits from tuna fish of the WCPO region?	Above 50	Yes, answered with the help	Medium	Search Pane	Cannot scroll to see the information at the bottom
8. Name one county which processes tuna and consumes it domestically (processing to market), closed-loop interactions.	Above 50	Yes, Answered with help	High	Flow Map	Could not scroll to see the legend. Slightly confused with the terms used in the values supply chain resource, fleet, process to market.

Section B: Part II – Satisfaction Testing

Measure	Question	Results
Discretionary usage & Satisfaction with features	1. Is the visualization misleading/ ambiguous e.g. does it convey confusing information?	Overall good application 4/5 Yes, the data discrepancies are somewhat misleading and the meaning of %share in the bar chart is also confusing.
Satisfaction with features	2. Is the choice of colours suitable?	5/5, Suitable- no opinion perhaps gradient colour for added direction.
Feature utilization & Discretionary usage	3. What is the best use of this visualization?	Have a general overview of the supply value chain and who are the key actors in the industry. Very suitable for fisheries management and policy to have a holistic picture and see how many countries the key beneficiaries are. Good for understanding underlying data in some cases.
Overall satisfaction	4. How easy is it to use the visualizations?	Moderately easy
Overall satisfaction	5. Kindly rate out of 1 to 5 how easy you found the following visualizations	Bar chart – 2 / 5 Flow map – 4/ 5 Sankey Diagram– 4/ 5 Distribution maps – 3/5

Section C: Interview and Additional Notes

Any suggestions for improvements	- Data values are misleading in relation to % share, replace 0 with missing data hence distribution maps are confusing. Check on data accuracy. - The terminology used in the fisheries value chain can be a bit confusing, explanation on the terms used would help. e.g. distinguish resources from the fleet. - Change the location of Europe to EU Commission capital. - Explain the meaning of % share distribution - Information on About should state the mapped data is a part of the report on the economic benefits from purse seine fishing gear in WCPO not for the entire project. Check on the introduction statement. - More clearly defined ecological boundaries. - If possible, include the fishing boundaries e.g. EEZ's. -Fix scrolling for other screens.
Are all functionalities useful and what could be removed?	Yes, they all are. None - Like the flow map very much and its affordance in direction using animation. - Very aesthetically pleasing and intuitive to use.

User 2

Section A: Tester's Profile Results

User	Profile		Results
TP 2	Age group		25 - 35
	Highest Level of completed education		Master
	Educational Background		Agriculture, Gender and Development Studies
	Main occupation		Research and Climate Action Project Coordinator, CIAT
	Technical expertise	Experience using maps	Yes, somehow
		Familiarity with interactive maps and web applications	Yes
		Familiarity with interactive map functions	Yes
	Domain Knowledge	Are you familiar with Marine Ecosystem Service Flows?	No
	Use Case knowledge	Familiarity with the WCPO fisheries and the Pacific Possible Project reports?	No
		If involved in what capacity or work?	n/a

Section B: Part I - Task Analysis Results Effectiveness and Efficiency

Questions	Time (sec)	Accuracy	Difficulty	Target Visual	Notes/comments
1. What is the largest benefit type of Papua New Guinea with country code PG?	10 – 50	Yes	Low	Bar Chart	Only used the bar chart, explain what is "dist" short form for?
2. What is the weight in % share distribution of tuna fish caught by Micronesia with country code FM as a resource owner?	10 – 50	Yes	Low	Bar Chart	No comment
3. What countries does Taiwan export tuna fish to for processing?	10 – 50	Yes	Medium	Flow map & Sankey	I cannot use the flow map because I do not know the countries, Sankey is more useful.
4. Which regions do most countries export processed tuna to for consumption (largest markets)?	Above 50	No	High	Flow Map & Sankey	Do not understand if the question refers to using Sankey or flow map and confused by the Sankey positions

5. Which is the largest processing location of fish by weight in metric tons?	Above 50	Yes	High	Distribution maps	Not very easy to just keep hovering over the maps due to small countries.
6. Which country has the highest percentage of fleets fishing in WCPO?	Above 50	Yes	High	Distribution maps	Used flow map.
7. What is the main way that China benefits from tuna fish of the WCPO region?	10 – 50	Yes	Medium	Search Pane	Used overview as well
8. Name one county which processes tuna and consumes it domestically (processing to market), closed-loop interactions.	10 – 50	Yes, Answered with help	High	Flow Map	Could not scroll app is cut halfway.

Section B: Part II – Satisfaction Testing

Measure	Question	Results
Discretionary usage & Satisfaction with features	1. Is the visualization misleading/ ambiguous e.g. does it convey confusing information?	4/5 Interactions are intuitive Legend is confusing for flows more clarity needed
Satisfaction with features	2. Is the choice of colours suitable?	Suitable
Feature utilization & Discretionary usage	3. What is the best use of this visualization?	Both detailed and general overview
Overall satisfaction	4. How easy is it to use the visualizations?	Simple and easy to use after explanation is provided
Overall satisfaction	5. Kindly rate out of 1 to 5 how easy you found the following visualizations	Flow Map – 4/5 Bar chart – 5/5; very intuitive Sankey Diagram - 3/5 Distribution maps – 4/5

Section C: Interview and Additional Notes

Any suggestions for improvements	- Sankey was confusing because of complexity on how flows move - How its arranged is also not easy to understand the order chosen for countries. Why are there unlinked countries? -Allow for scrolling - Zooming together with panning could make the map more useable.
Are all functionalities useful and what could be removed?	None - A flow map is very good for overview information on the supply chain.

User 3

Section A: Tester's Profile Results

User	Profile		Results
TP 3	Age group		18 - 25
	Highest Level of completed education		Masters
	Educational Background		Geoinformatics
	Main occupation		GIS Analyst, student
	Technical expertise	Experience using maps	Yes, high level
		Familiarity with interactive maps and web applications	Yes
		Familiarity with interactive map functions	Yes
	Domain Knowledge	Are you familiar with Marine Ecosystem Service Flows?	No
	Use Case knowledge	Familiarity with the WCPO fisheries and the Pacific Possible Project reports?	No
		If involved in what capacity or work?	n/a

Section B: Part I - Task Analysis Results Effectiveness and Efficiency

Questions	Time (sec)	Accuracy	Difficulty	Target Visual	Notes/comments
1. What is the largest benefit type of Papua New Guinea with country code PG?	10 – 50	Yes	Low	Bar Chart	Intuitive bar chart
2. What is the weight in % share distribution of tuna fish caught by Micronesia with country code FM as a resource owner?	10 – 50	Yes	Low	Bar Chart	Easy to use the bar chart
3. What countries does Taiwan export tuna fish to for processing?	10 – 50	Yes	Low	Flow map & Sankey	Used Sankey which was quite straight forward.
4. Which regions do most countries export processed tuna to for consumption (market)?	Above 50	No	High	Flow Map & Sankey	Do not understand if the question wants the largest or and the Sankey positions are confusing to know where market and processing is.
5. Which is the largest processing location of fish by weight in metric tons?	Above 50	Yes, answered with help	High	Distribution maps	Not sure whether to hover on all, my next best option is to use the bar chart.

6. Which country has the highest percentage of fleets fishing in WCPO?	Above 50	Yes, answered with help	Medium	Distribution maps	Same issue not sure if I hovered overall.
7. What is the main way that China benefits from tuna fish of the WCPO region?	10 - 50	Yes	Low	Search Pane	Very intuitive
8. Name one county which processes tuna and consumes it domestically (processing to market), closed-loop interactions.	Above 50	Yes, Answered with help	High	Flow Map	A bit confusing because of overlapping flows. Adjust so that filtering can be fixed on one type of flow when clicked not mouse hover.

Section B: Part II – Satisfaction Testing

Measure	Question	Results
Discretionary usage & Satisfaction with features	1. Is the visualization misleading/ ambiguous e.g. does it convey confusing information?	4/5 Very good intuitive application, however, legend hover should be fixed.
Satisfaction with features	2. Is the choice of colours suitable?	5/5, Suitable
Feature utilization & Discretionary usage	3. What is the best use of this visualization?	Both general and detailed
Overall satisfaction	4. How easy is it to use the visualizations?	Moderately easy
Overall satisfaction	5. Which visualization did you find more straightforward, easy to understand?	Flow Map – 3/5 Bar chart – 5/5 Sankey Diagram – 4/5 Distribution maps – 4/5

Section C: Interview and Additional Notes

Any suggestions for improvements	- Why do small unlinked countries in the Sankey diagram exist? - Fix legend filter to allow clicking on and off.
Are all functionalities useful and what could be removed?	None - Otherwise, very beautiful and useful visualizations. - The Sankey diagram is quite interesting and how it is linked to the flow map.

User 4

Section A: Tester's Profile Results

User	Profile		Results
TP 4	Age group		25 – 35
	Highest Level of completed education		Master
	Educational Background		Biosystems Engineering, Water and Sanitation
	Main occupation		Research and Development Engineer – Water purification systems & technologist
	Technical expertise	Experience using maps	Yes, somehow
		Familiarity with interactive maps and web applications	Yes
		Familiarity with interactive map functions	Yes
	Domain Knowledge	Are you familiar with Marine Ecosystem Service Flows?	No
	Use Case knowledge	Familiarity with the WCPO fisheries and the Pacific Possible Project reports?	No
		If involved in what capacity or work?	n/a

Section B: Part I - Task Analysis Results Effectiveness and Efficiency

Questions	Time (sec)	Accuracy	Difficulty	Target Visual	Notes/comments
1. What is the largest benefit type of Papua New Guinea with country code PG?	10 – 50	Yes	Low	Bar Chart	No comment
2. What is the weight in % share distribution of tuna fish caught by Micronesia with country code FM as a resource owner?	10 – 50	Yes, answered with help	Low	Bar Chart	The bar chart is easy to use
3. What countries does Taiwan export tuna fish to for processing?	0 – 10	Yes	Low	Flow map & Sankey	Easy to use Sankey diagram more than flow map
4. Which regions do most countries export processed tuna to for consumption (market)?	10 – 50	No	High	Flow Map & Sankey	Not sure what the centre of Russia means, what should I look at how many flows are moving or the Sankey?
5. Which is the largest processing location of	0 – 10	Yes	Medium	Distribution maps	Quite clear, but someone has to keep hovering

fish by weight in metric tons?					
6. Which country has the highest percentage of fleets fishing in WCPO?	10 – 50	Yes	Medium	Distribution maps	Same as above
7. What is the main way that China benefits from tuna fish of the WCPO region?	Above 50	Yes	Medium	Search Pane	Very good search tool. Link it to the map to zoom or highlight the country
8. Name one county which processes tuna and consumes it domestically (processing to market), closed-loop interactions.	Above 50	Yes, Answered with help	High	Flow Map	Confusing because there are two colours in Japan.

Section B: Part II – Satisfaction Testing

Measure	Question	Results
Discretionary usage & Satisfaction with features	1. Is the visualization misleading/ ambiguous e.g. does it convey confusing information?	4/5 A clearer title and subtitle could be provided that is more descriptive.
Satisfaction with features	2. Is the choice of colours suitable?	5/5 Neutral
Feature utilization & Discretionary usage	3. What is the best use of this visualization?	To answer specific details and make decisions on what each country's role is in the tuna fishing industry.
Overall satisfaction	4. How easy is it to use the visualizations?	Simple and easy to use
Overall satisfaction	5. Which visualization did you find more straightforward, easy to understand?	Flow Map – 5/5 Bar chart – 3/5 (Requires explanation) Sankey Diagram – 5/5 Distribution maps – 4/5

Section C: Interview and Additional Notes

Any suggestions for improvements	- At first glance, one can understand the visuals but to derive detailed information one needs explanation or information. - App Title can have sub-title to be more informative. - It would also be good to have Map titles for every map - The bar chart requires further explanation. The y-axis especially needs to be changed e.g. the % proportion of tuna over the total per beneficiary type. - The centre of the map used is confusing as I am used to a map centred on Africa near Greenwich Meridian.
Are all functionalities useful and what could be removed?	Yes, they all are. None - Overall, very good but requires a bit of training. - The search key is very easy to use - Very relevant in current business and supply chain management and should investigate replicating for other product chains.

User 5

Section A: Tester's Profile Results

User	Profile		Results
TP 5	Age group		35 – 50
	Highest Level of completed education		Doctor
	Educational Background		Ph.D. in Soil Science and MSc in Soil Science
	Main occupation		Assistant Professor in Ecosystem Services and Land-use change
	Technical expertise	Experience using maps	Yes, high level
		Familiarity with interactive maps and web applications	Yes
		Familiarity with interactive map functions	Yes
	Domain Knowledge	Are you familiar with Marine Ecosystem Service Flows?	Yes
	Use Case knowledge	Familiarity with the WCPO fisheries and the Pacific Possible Project reports?	No
		If involved in what capacity or work?	n/a

Section B: Part I - Task Analysis Results Effectiveness and Efficiency

Questions	Time (sec)	Accuracy	Difficulty	Target Visual	Notes/comments
1. What is the largest benefit type of Papua New Guinea with country code PG?	10 – 50	Yes	Low	Bar Chart	No comment
2. What is the weight in % share distribution of tuna fish caught by Micronesia with country code FM as a resource owner?	0 – 10	Yes	Low	Bar Chart	The bar chart is easy to use
3. What countries does Taiwan export tuna fish to for processing?	10 – 50	Yes	Medium	Flow map & Sankey	No comment
4. Which regions do most countries export processed tuna to for consumption (market)?	Above 50	No	Medium	Flow Map & Sankey	Why are there countries that are not connected?
5. Which is the largest processing location of	Above 50	Yes	Medium	Distribution maps	Quite clear, but colours variations might be too many.

fish by weight in metric tons?					
6. Which country has the highest percentage of fleets fishing in WCPO?	Above 50	Yes	Medium	Distribution maps	Rename Papua New Guinea to PNG in the search
7. What is the main way that China benefits from tuna fish of the WCPO region?	10 – 50	Yes, answered with help	High	Search Pane	No comment
8. Name one county which processes tuna and consumes it domestically (processing to market), closed-loop interactions.	Above 50	Yes, Answered with help	High	Flow Map	I can see that Japan is both red and blue, can be a bit tricky but that is good that you can toggle the flows. Provide explanation to allow toggling

Section B: Part II – Satisfaction Testing

Measure	Question	Results
Discretionary usage & Satisfaction with features	1. Is the visualization misleading/ ambiguous e.g. does it convey confusing information?	4/5 Understanding the magnitude needs explanation. Linkage and the kind of flows moving is well displayed.
Satisfaction with features	2. Is the choice of colours suitable?	4/5, Too many shades of blue Flows colours are good. Check on the colours of Sankey diagram to distinguish red and green for colour blindness Some countries have the same colours.
Feature utilization & Discretionary usage	3. What is the best use of this visualization?	It can easily show a general overview, detailed information needs a bit of retraining.
Overall satisfaction	4. How easy is it to use the visualizations?	Simple and easy to use
Overall satisfaction	5. Which visualization did you find more straightforward, easy to understand?	Flow Map – 4/5 Bar chart – 5/5 Sankey Diagram – 4/5 Distribution maps – 4/5

Section C: Interview and Additional Notes

Any suggestions for improvements	- Explain the ability to toggle flow layers by hovering over legend. - Check the colours for colour-blindness - Too many shades of blue to discern the highest value - Placement of the buttons of switching distribution maps can be placed above the map and not above the bar chart. - Panels for the map could be made larger and reduce panel size for bar chart and Sankey.
Are all functionalities useful and what could be removed?	Yes, they all are. None

APPENDIX C: USABILITY TEST QUESTIONNAIRE 2ND EVALUATION

Usability Testing Sample Questionnaire for the 2nd Evaluation

Mapping of flows of benefits from marine ecosystems across the globe: Interactive Web Mapping Application – 2nd User Testing

This survey seeks to assess the suitability in use of the created interactive web mapping visualizations for the chosen case of the fisheries from the Western Central Pacific Ocean (WCPO) Region.

Background

Using the case of the WCPO fisheries, better communicating the current baseline data is important in analysing and understanding the current situation and its drivers of change for decision making and scenario analysis and it also enables information that was previously not considered in fisheries management to be considered. The visualization provides an alternative communication tool of the baseline information to describe the global supply chain of these benefits across the globe. An interactive web mapping tool has therefore been created for this purpose and this survey tests the usability of the tool. The overall aim of the prototype is *"To communicate the flows of economic benefits of Marine Ecosystem Services across the globe for the case of WCPO purse seine tuna fisheries"*.

Identified use purposes for the Prototype:

1. To have a general view of beneficiary distributions in each segment.
2. To find out distribution per different types of benefits (resource, fleet/harvest, and processing).
3. To determine detailed information of the beneficiaries.
4. To see the relationship between that locations and understand the movement and direction of these flows.

Interview

This survey is the 2nd round of porotype testing. As a test participant you had already participated in the first round of user testing where you provided recommendations for prototype adaptation. This is now a follow-up to determine if most of the usability issues were met in the adapted prototype and determine from a user's perspective which issues remain to be resolved. The survey will begin with a re-introduction of the aim of the application, the purpose it serves and the functionalities available and a summary of some of the usability issue that arose in the previous interview.

The interview will take 20 minutes. First take 5minutes to explore the application and point out the issues that you previously experienced and hoped to be resolved then answer the following questions.

MAPPING FLOWS OF BENEFITS FROM MARINE ECOSYSTEMS ACROSS THE GLOBE

1. How would you rate the ease of use of the application after the adaptations on a rating of 1 to 5?

   Bar chart –
   Sankey Diagram –
   Flow map –
   Distribution maps –

2. What are the general issues that you think still exists that are crucial for the end-user?

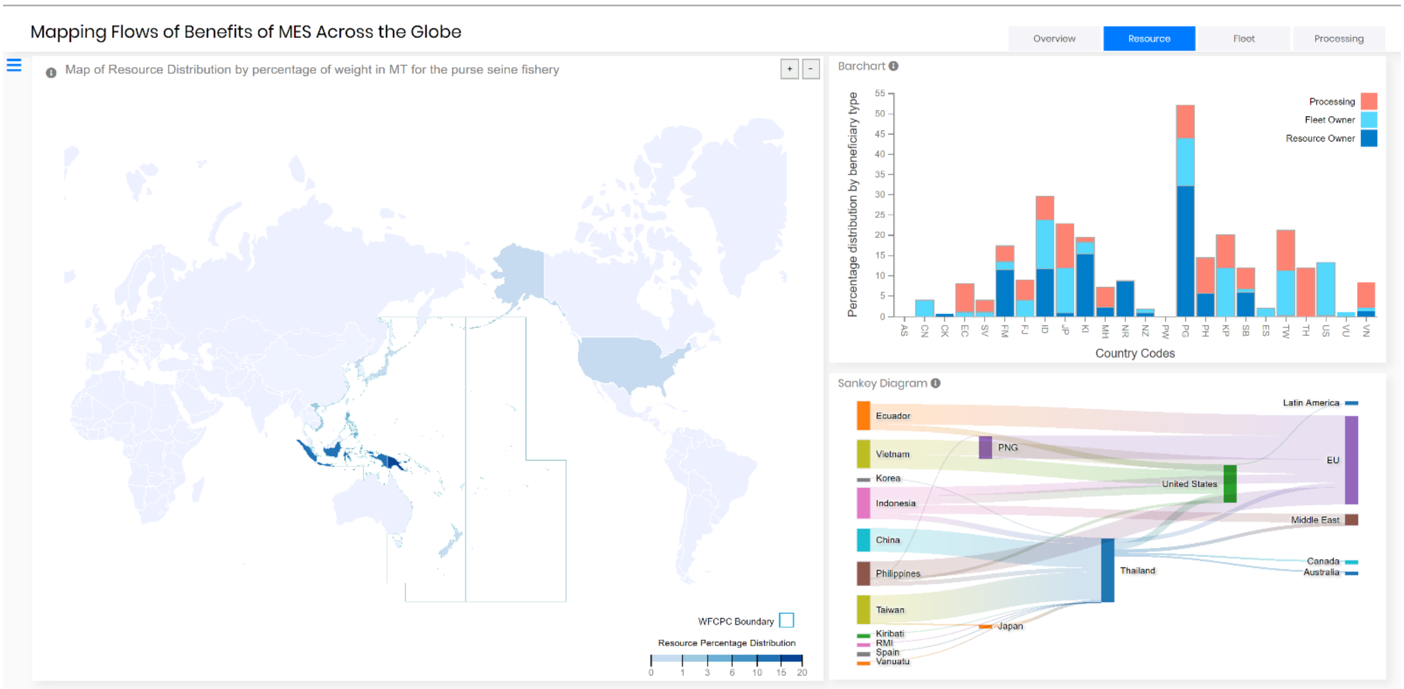
3. Do you think the application can help achieve the defined goal and use purpose? If no, why?

4. Do you think this application may be useful for decision making in Marine Ecosystem Services? If no, why?

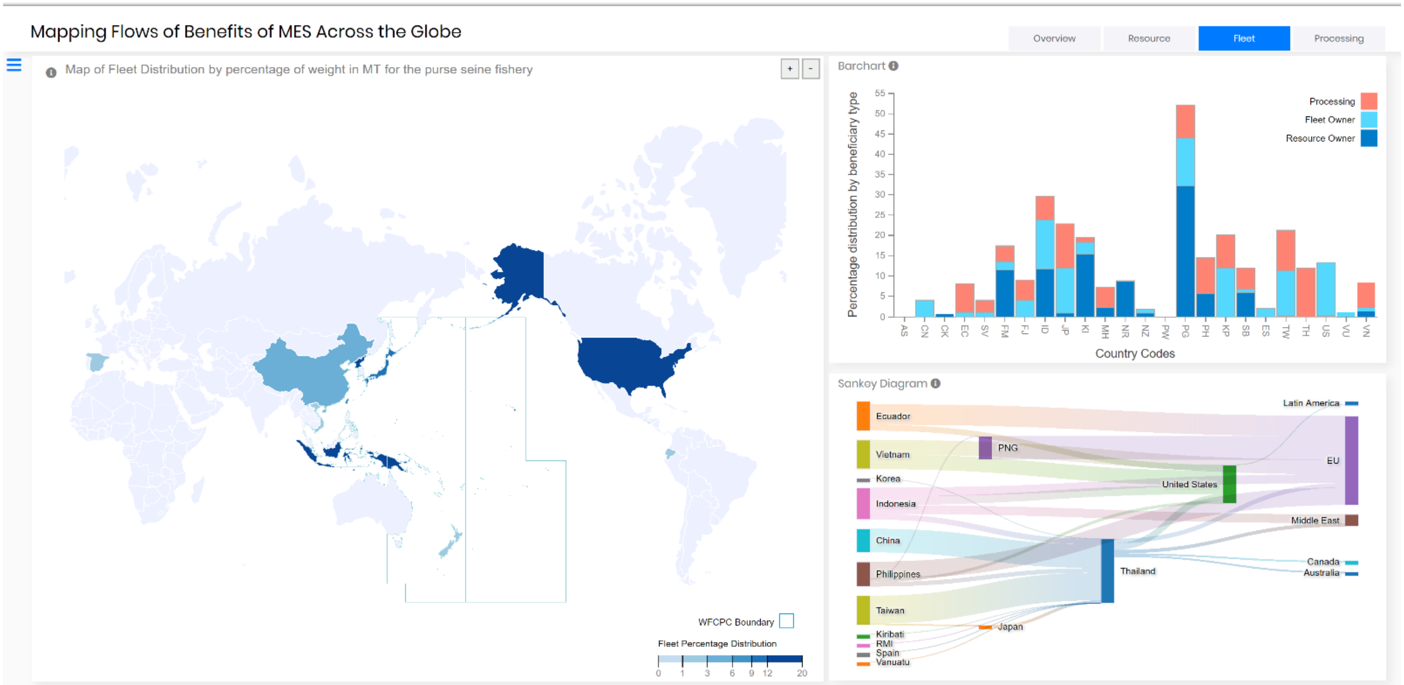
5. Which other areas would you suggest useful for reproducing such a visualization?

APPENDIX D: PROTOTYPE INTERACTIVITY FUNCTIONS

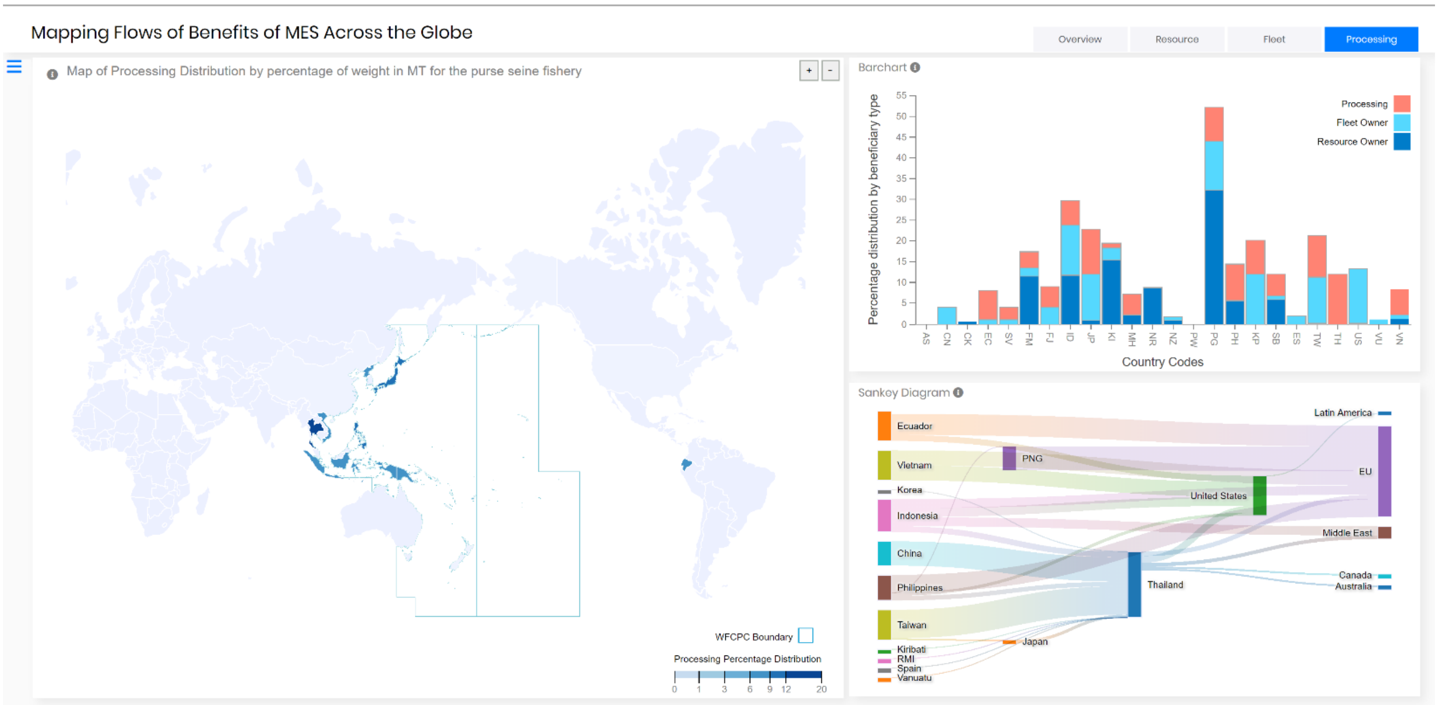
1. Multiple Views of Map Panel: Clicking on Resource Owners



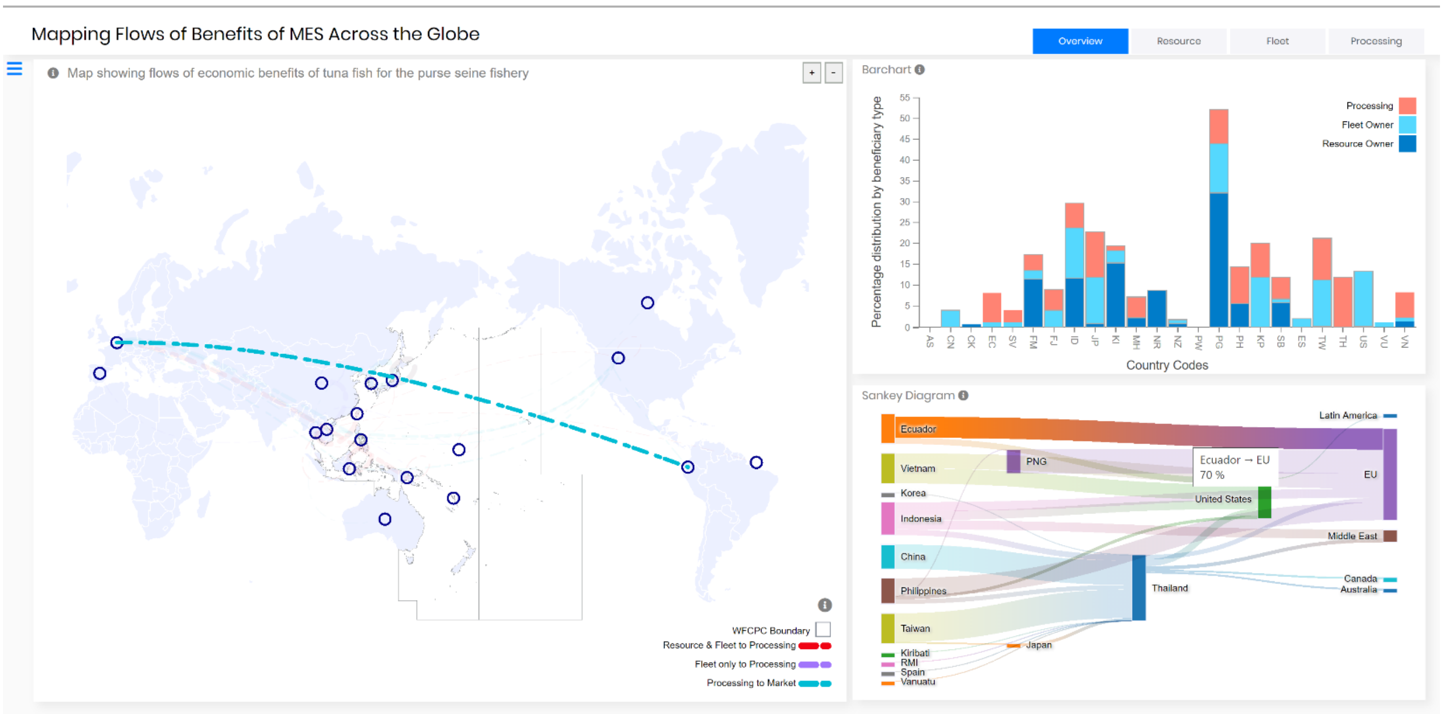
2. Multiple Views of Map Panel: Clicking on Fleet Owners



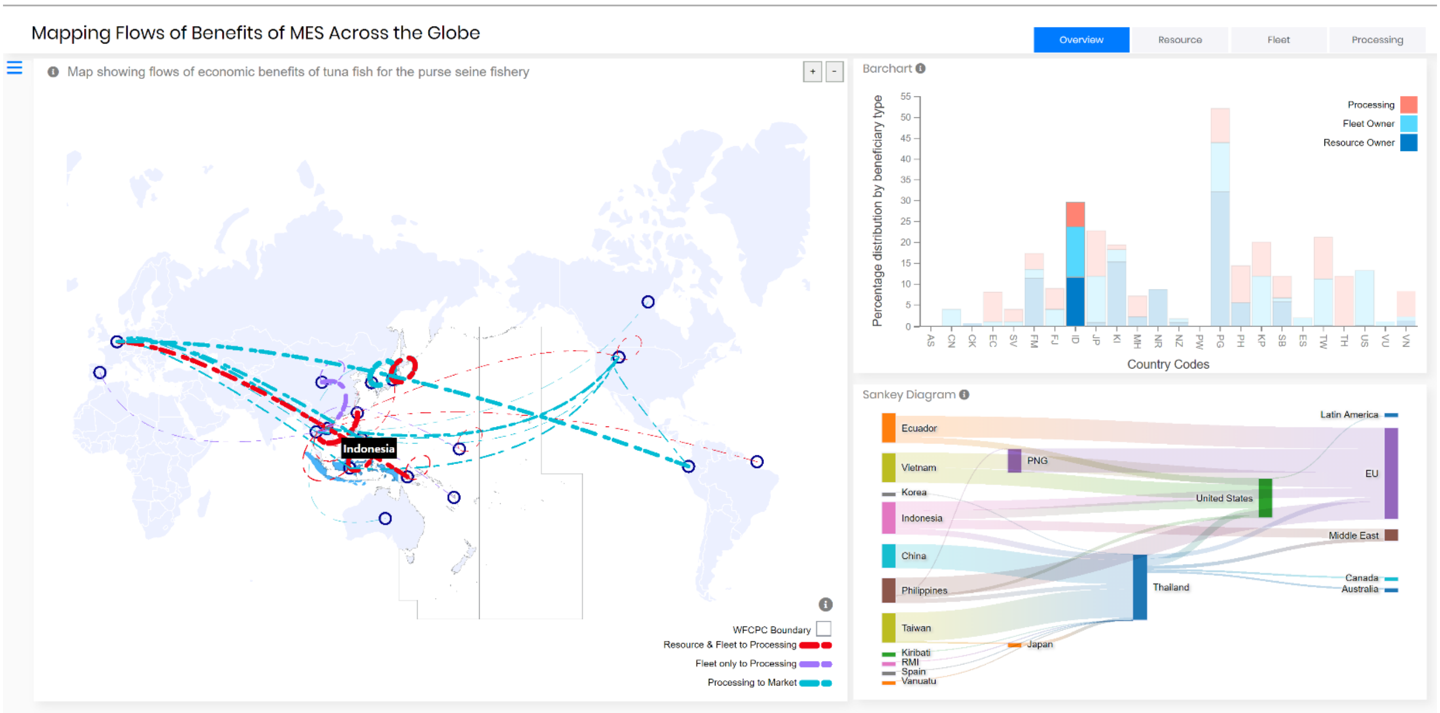
3. Multiple Views of Map Panel: Clicking on Processing



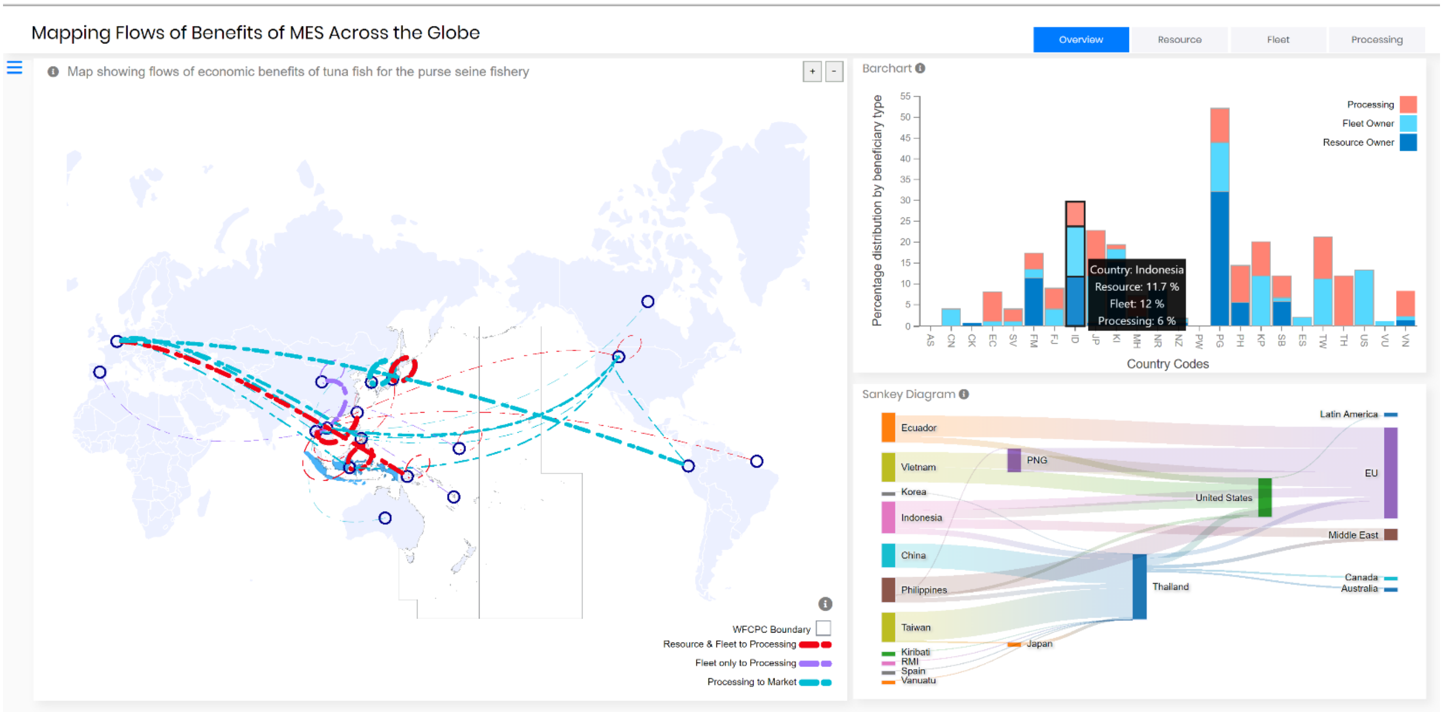
4. Flow map and Sankey Interactivity: Hovering over Sankey



5. Stacked bar chart and Countries: Hovering over countries



6. Stacked bar chart and Countries: Hovering over the Stacked bar chart



7. Stacked bar chart and Countries: Filtering flows by clicking on legend items