CERTIFICATE COMPLEMENTAIRE EN GEOMATIQUE

METHODOLOGIES FOR ESTIMATING CARBON STOCK, FLUXES, AND HUMAN DISTURBANCE BY UTILIZING BIG DATA SOURCE AND GEO-SPATIAL DATA

INTERNSHIP THESIS

BY JAWAD MONES

SUPERVISOR: DR. PIERRE LACROIX

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Declaration of Authorship

“I declare in lieu of oath that, the entire contents of this thesis are my own work except where otherwise indicated. All references and literal extracts have been quoted clearly. Information sources of figures, charts, and tables have been acknowledged. This thesis has not been submitted to any other institution and has not been published.”

Date: ______________________ Signature: _________________________

ABSTRACT

Blue carbon was first time coined in 2009 and is defined as a carbon captured by living organisms in ocean and stored in the forms of sediments from mangroves, seagrass, and salt marshes. In other words, blue carbon is the carbon that is captured by world's oceans, and it represents more than 55% of green carbon. These three ecosystems (mangroves, seagrass, and salt marches) are essential and effective in terms of global carbon sinking. In contrast to the rainforests that are able to store the carbon for decades or centuries, blue carbon ecosystems stored carbon for millennia. The total sink capacity of organic carbon by blue carbon ecosystem is estimated to be 0.22 – 0.88 Pg C/year globally. This is equal to the 0.6 – 2 % of global anthropogenic CO2 emission or equal to 49 Pg CO2 /year Moreover, the beds of this ecosystem account for less than 0.5% of the ocean area but it accounts for 50-70% of total carbon stocked in marine sediments.

Preserving blue carbon ecosystem provides enormous positive effects on local and national economics. It boosts standard living and food safety as well as enhance the ability of people living in coastal area to cope with the effects of climate change.

In this work, MapX, an online open-source platform, was used to help visualize blue carbon extent, type, and their habitats at the global level. A specific workspace with different geospatial data was created to illustrate the extents and its evolution over time.

A dashboard in the Apache Superset platform was created and used to represent data related to the blue carbon ecosystems (especially, mangrove) graphically.

Acknowledgement

Firstly, I would like to express my deepest appreciation to my supervisor Dr. Pierre Lacroix for his assistance, suggestions, comments, and patience.
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Cs	Cesium
CO2	Carbon dioxide
GIS	Geographic information system
GRID-Geneva	Global Resource Information Database, Geneva office
IUCN	International Union for Conservation of Nature
LDAP	Lightweight Directory Access Protocol
OGC	Open Geospatial Consortium
Pb	Plumbum (lead)
Pg	Petagram
QGIS	Quantum Geographic Information System
RSET method	Road Surface Elevation Table method
SQL	Structured Query Language
SQS	Sample Queue Service
SOC	Soil organic carbon
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Program
UNEP-WCMC	UN Environnement Programme World Conservation Monitoring Centre

Chapter 1 Introduction

1.1 Preamble

During my Certificate of Geomatics at University of Geneva, I had the opportunity to do a research thesis on the following topic: *Methodologies for estimating carbon stock, fluxes, and human disturbance by utilizing big data sources and geospatial data.* This research was undergone at UNEP/GRID-Geneva, which is a UNEP bureau specialized in transforming raw data into information and knowledge, in many environmental fields, including climate change and biodiversity.

1.2 Background to the study

Marine ecosystems play a crucial rule for securing humanity's future health and well-being. The part of marine ecosystems that contribute to climate change mitigation by significant carbon sequestration from the atmosphere is known as: blue carbon ecosystems(Laffoley, 2020). Blue carbon ecosystems have high carbon storage rates per unit area and gathered carbon in their soils and sediments. These ecosystems are mangroves, seagrasses, and salt marshes, which build up large stocks of organic carbon in the coastal zones. These ecosystems also have high capacity of carbon storage, and they can store up to one thousand tons of carbon per hectare, which is much higher than terrestrial ecosystems. However, climate change and anthropogenic activities cause damaged on blue carbon ecosystems.

1.3 Problem statement and research approach

Coastal ecosystems, more specifically mangroves, tidal marshes, and seagrasses are extremely important for human well-being and global biodiversity and provide enormous benefits and services that lead people to adapt to, deal with, and mitigate the impacts of climate change. Climate change and extreme anthropogenic drivers consist of coastal population growth, conversion of river flows, overfishing, forestry, agriculture, pollution, and other land use changes that threaten the preservation of vegetated coastal ecosystems such as seagrasses and mangroves, and tidal marshes. To understand these impacts on blue carbon ecosystems, the potential for ecosystems to combat the consequences of those impacts, and to have an overview both in space and time, the present study uses geospatial and statistical data. For this, we created a workspace in a geographic information system (GIS) and visualized geospatial data related to these impacts on blue carbon ecosystems.

1.4 Research Question

Main questions related to this work are:

- How local ecosystem contribute to sequestration and sediment carbon storage?
- How carbon sequestration and storage are affected by climate change?

1.5 Objectives of the Work

From a technical perspective, the main objectives of the internship are:

- To collect and prepare data related to blue carbon ecosystems, blue carbon stocks, human disturbances by using different GIS software such ArcGIS Pro, QGIS, and RStudio.
- To visualize blue carbon ecosystems extent, blue carbon stocks, and anthropogenic impacts using a GIS such as MapX (mapx.org).
- To create dashboards on Apache Superset to visualize data related to blue carbon ecosystems.

Chapter 2 Methodology and Literature Review

2.1 Methodology

Methodology is based on an extensive literature review as well as geospatial and statistical data collection, preparation and publication in MapX and Apache Superset.

For what concerns the geospatial aspects, the method used in this work is based on objectives formulated in1.5 MapX is used for creating a workspace related to the blue carbon ecosystem. Before creating the workspace in MapX, several tables and layers were prepared through the ArcGIS Pro, QGIS, and RStudio software before using them in MapX. During the work, 11 geo-spatial layers were created and 33 were imported from different workspace to visualize data about the blue carbon ecosystems such as mangrove, seagrass, and salt marsh. Furthermore, to better understand the extent, stock and human disturbances of blue carbon ecosystems and those topics and views relevant to it, views were shared from different MapX workspaces that were already there in MapX. Moreover, to address objectives formulated in 1.5, a dash-board was created in Apache Superset online open-source application.

The primary data for this work was based on previous studies and finding of location and in-ternational institutions such as UNEP/GRID-Geneva, University of Geneva, UNEP-WCMC, Re-source Watch, Nasa, Esri, NASA's Socioeconomic Data and Application Center (SEDAC), Panegea, UNEP Environmental, Natural Earth.

The qualitive and quantitative data collection of this work is based on the research and survey which was conducted by Tomohiro kuwae & Masakazu Hori (2019), Alongi (2018), Duke (2016), and many others that are mentioned in the references list.

2.2 Literature Review

2.2.1 Brown, black, and green carbon

Anthropogenic climate change is caused by the increasing volume of greenhouse gases and particles in the atmosphere. It caused firstly by burning of fossil fuels and disturbing green-house gases in the form of CO2 refers to brown carbon and dust particles resulting from impure combustion such as soot and dust refers to the black carbon; secondly by emissions destroying natural vegetation, forest fires and agriculture emission and thirdly, by lessened ability of natural ecosystems to bind carbon through photosynthesis and store it – referred to green carbon.

Brown and black carbon emissions that are produced from burning fossil fuels, biofuels, and wood burning account as a major contributor to global warming. Moreover, black carbon emissions have an enormous effect on radiation transmission into troposphere. Its transmission could be both directly and indirectly through the clouds and reduce the snow and ice albedo (Nellemann & Corcoran, 2009). Black carbon is thought to be the second largest contributor to global warming after brown carbon. Hence, preventing and decreasing of black carbon emissions could be one of the most efficient ways for mitigating global warming. Black carbon can enter in the ocean through aerosols and river deposition and can comprise up to 30 % of sedimentary organic carbon (SOC) in some areas of deep see. Black carbon is thought to be responsible for around 25 % of observed global warming over the past century. It is believed that black carbon remains in the atmosphere for days-weeks, whereas CO2 remains approximately one hundred years in the atmosphere.

Green carbon is a vital part of global carbon cycle and refers to those carbon that removed by photosynthesis and store in the plants and soil of natural ecosystems. Compared to many plants and most corps which release much of their carbon at the end of each season, forest biomass can accumulate large amounts of CO2 in a brief period and can store them for several decades.

2.2.2 Blue Carbon Ecosystem

The blue carbon was first time coined by (Nellemann & Corcoran, 2009) and is defined as a carbon captured by living organisms in ocean and stored in the form of sediments from mangroves, seagrass, and salt marshes. In other words, blue carbon is a form of carbon that is captured by world's oceans, and it represents more than 55% of green carbon. These three ecosystems, mangroves, seagrass, and salt marches are essential and effective in terms of global carbon sinking. In contrast to the rainforests that can store the carbon for decades or centuries, blue carbon ecosystem can store carbon for millennia. The long-term rate of carbon aggregation in sediment for this ecosystem vary whether we consider mangroves (139 gC/m2 /year), seagrass (eighty-three gC /m2 /year), salt marches (210 gC / m2 /year) (Laffoley & Grimsditch, 2009). In other words, the total sink capacity of organic carbon by blue carbon ecosystems is estimated to be 0.22 – 0.88 Pg [1]C/year globally. This is equal to the 0.6 – 2 % of global anthropogenic CO_2 emissions, or equal to 49 Pg CO_2 eq/year. Moreover, the bed of this ecosystem accounts for less than 0.5% of the ocean area but it accounts for 50-70% of total carbon stocked in marine sediments. The plant biomass of these ecosystems consists only 0.05% of total terrestrial plants but the amount of carbon stored is equivalent to the terrestrial plants on the earth (Kuwae & Hori, 2019). The carbon sequestration rate for these ecosystems is 212 ± 18 g Corg/m2/ year for salt marches, 171 ± 17.1 g Corg/m2/year for mangroves, and for seagrass 220 ± 20.1 g Corg/m2/ year (Alongi, 2018).

However, climate change and extreme anthropogenic activities impact the blue carbon ecosystem that become the most rapidly disappearing ecosystem on the earth. The rate of disappearing is four times higher than the tropical forests and is equal to 2-7% per year (Kuwae & Hori, 2019). In addition, the amount of CO_2 emissions produced from the loss of blue carbon ecosystems is 0.15-1.02 Pg CO_2/year equivalent to 3-19% total CO_2 emission that from terrestrial land-use change. This number for CO_2 emissions from mangrove deforestation is 0.21-0.45 Pg CO_2/year globally (Arias-Ortiz et al., 2018; Hamilton & Friess, 2018).

Preserving blue carbon ecosystem can provide enormous positive effects on local and national economics. It should boost standard living and food safety as well as enhance the ability of people living in coastal area to reconcile with the effects of climate change. Despite the fact that coastal areas represent only 7% of total ocean area, blue carbon ecosystems play an essential role in fishing grounds that provide 50% of their worldwide resources. Around three billion people rely on nutrition which is essential for life activities provided by coastal areas. Meanwhile, 50% of animal protein and minerals that are consumed by four billion people living in developing countries is provided by coastal areas.

[1] Peta gram

In relation to the human society, blue carbon ecosystems also provide wide ranges of benefits alongside fishery resources. These benefits are water purification, reduced coastal pollution, increased soil stability, increased nutrient supplies, reduction of effects of extreme weather events, decreased coastal erosion, and protection of coastline. The value of the above ecosystem services has been estimated twenty-five trillion dollars per year(Kuwae & Hori, 2019).

Mangrove

Mangrove forests are a part of blue carbon ecosystem, and they are composed of woody trees and scrubs that living along many coastal areas within low latitude. According to the(Alongi, 2018) mangrove forest attains peak luxuriance in sheltered muddy area where quiescent conditions foster establishment and growth of propagules, but they do occur on rocky and sand shores. By growing above mean seal-level, mangrove forest trees can trap silt and clay particles which brought in by tides and rivers to help consolidate and deposits on which they grow. Like salt marshes, mangrove intertidal zone is highly dynamic in terms of space and time, and it can be disturbed often by storms and cyclones, disease, pests, and anthropogenic intrusions. However, mangroves have high robust and adaptable to ever-changing conditions that can persists towards the harsh environment, daily tides and seasonal variations in temperature, salinity and anoxic of soils(Kuwae & Hori, 2019). There are around seventy species of mangrove which belong to the forty genera and twenty-five families. Twenty-five species are belonged to the families of Rhizophoraceae and Avicenniaceae.

The mechanisms of capturing and accumulating sediment and carbon in mangrove is different than for the other blue carbon ecosystems. Mangrove has ability to facilitate the capturing and storing of sediment particles and associated carbon into soil horizon. It also captures sunlight to boost up growth and production of above and below-ground biomass. Based on figure 2.1, the soil accretion rate) of mangrove forests average is 5.8 mm/year worldwide.

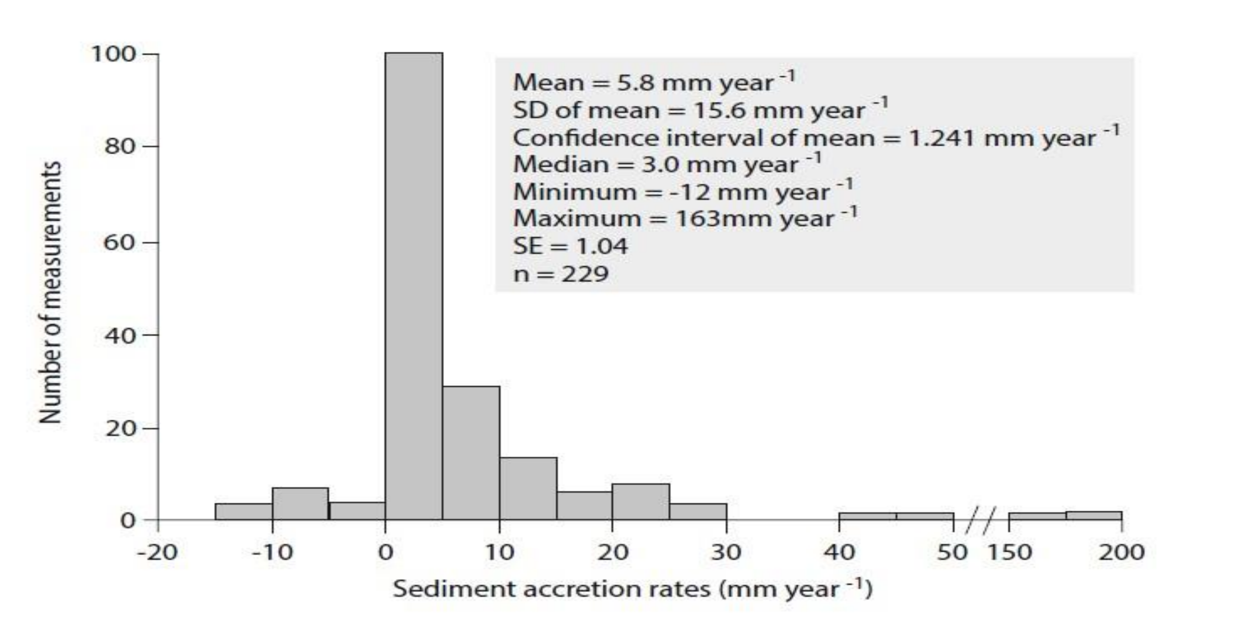

Figure 2-1 Soil accretion rates measured in various mangrove forests worldwide. Source: (Alongi, 2018)

The median is 3mm/year with one standard error of 1 mm/year according to the number of samples n =229. The average carbon sequestration rate for mangrove is 171 ± 17.1 g Corg /m2/ year. On the other hand, the values for mangrove carbon sequestration rate ranges from 1 to 1053 g Corg /m2 /year. There is no clear relationship between the carbon sequestration rate and the difference in latitude. The carbon sequestration rate of mangroves is a function of several parameters such as forest age, mangrove geomorphology, species composition, tidal inundation frequency, tidal elevation, soil grain size, catchment and river input, ocean input and degree of anthropogenic impact(Alongi, 2018).

Mangrove forests average carbon stock rates is 761 ± 45.5 Mg Corg/ha. The values range from 37 to 2477 Mg Corg /ha with a median of 723.4 Mg Corg /ha. By assuming a global mangrove area equals to 137’760 km2 and using the median value, the estimated total global carbon stock for mangroves is 10 Peta gram (Pg).

According to(Alongi, 2018; Kuwae & Hori, 2019) , on average, 91.8 % of total Corg stocks for this ecosystem is assigned to below-ground ecosystems (below-ground biomass and soil).

Seagrass

Seagrasses are intertidal and shallow subtidal habitats found on all continents except Antarctica. Seagrasses are composed of up to seventy-six species of marine angiosperms and they represent an important part of estuarines worldwide and coastal ecosystems in boreal, temperate, and tropical latitudes. Seagrass is crucial for economically valuable fishery species as it provides habitat, protection, and nursery grounds. It also acts as an indicator that modify local water quality and forms close links between benthic and pelagic food chains, and nutrient and carbon cycles(Unsworth et al., 2012). They are also important habitats for food security and human well-being, and they have an important level of connectivity with mangroves and coral reefs. Seagrasses like salt marshes and mangroves, have strong trophic links to the coastal ocean and are counted as one of the most productive primary producers in the sea.

Seagrass meadows are highly dynamic in terms of time and space with substantial changes taking place over short intervals. There are some factors that play key roles in influencing seagrass biomass, species composition and area. These factors are physical disturbance, herbivory (act of eating plants by animal, above or below ground), intraspecific competition, nutrients, pollution, and deposition of fine particles. Furthermore, there are number of factors will determine the occurrence of seagrass in any given area, including natural biophysical drivers that moderate physiological activity and morphology, like light availability, water clarity, temperature, salinity, currents, depth, wave action, substrate, nutrients, day length, epiphytes, and diseases (Kuwae & Hori, 2019).

According to the IUCN's Red List, around 24 % of all seagrass species are at risk of extinction and are classified as near threatened on that list (Short et al., 2011). The seagrass decline rate has increased from 0.9 % per year prior to 1940 to 7% per year since 1980. Direct and indirect impacts cause much of the permanent and chronic damages to seagrass meadows. Direct impacts are removal of seagrass during dredging and indirect impact are overfishing, long-term nutrient pollution and climate change (Kuwae & Hori, 2019). In relation to the carbon sinking in Southern Hemisphere, few metabolic studies have been conducted to define whether seagrass meadows have potential to sink carbon. However, only few studies available indicate that seagrass meadows have large storage capacity and can form the basis for climate change mitigation strategies in the Southern Hemisphere (Duarte et al., 2013).

Seagrasses act as an ecosystem engineer and have capability of reducing the velocity of currents and attenuating waves that enable sediment particles to deposit themselves on their surfaces and seabed. Other factors that play crucial roles in facilitating carbon accumulation, are canopy complexity, wave height, water depth and turbidity (Samper-Villarreal et al., 2016).

According to (Alongi, 2018; Kuwae & Hori, 2019), the average carbon sequestration rates for seagrass meadows from 396 samples in different countries is 220.7 ± 20.1 g Corg /m2/year and a median of 167.4 g Corg /m2/year. However, based on(Unsworth et al., 2012) the carbon storage of seagrass is less than salt marches and mangroves and it is estimated 155 g Corg /m2/ year. Seagrasses, unlike those blue carbon ecosystems, is able to modify sea water pH to the extent that this phenomenon may have helped them to withstand ocean acidification(Apostolaki et al., 2014).

In Figure 2-2,. most observation cores are lower than 1m depth with a value less than 100 Mg Corg / ha. However, most of the carbon inventories from cores greater than 1m depth, have a median value of 69.3 Corg /ha. These median value for above and below-ground biomass were 0.264 and 0.540 Mg Corg /ha respectively. These median values indicate that nearly all the seagrass organic carbon is stored in soil (Alongi, 2018)

By estimating the total seagrass area in the world, which is between 60’000 km2 and 300’000, and by multiplying this value by the median soil Corg value, we derive a range of global Corg values of between 2.1 and 2.4 Pg Corg for soils and between 75.5 and 151 Tg Corg for biomass (Alongi, 2018).

Carbon storage in seagrass soil reflects a long-term nutrient history. Armitage and Fourqurean found thatby comparing long-term nutrient history and short-term nutrient enrichment in sites subjected to 17 months of nutrient additions, biomass carbon storage of above and below increases. However, soil carbon content decrease by about 10 % due to the phosphorus additions.

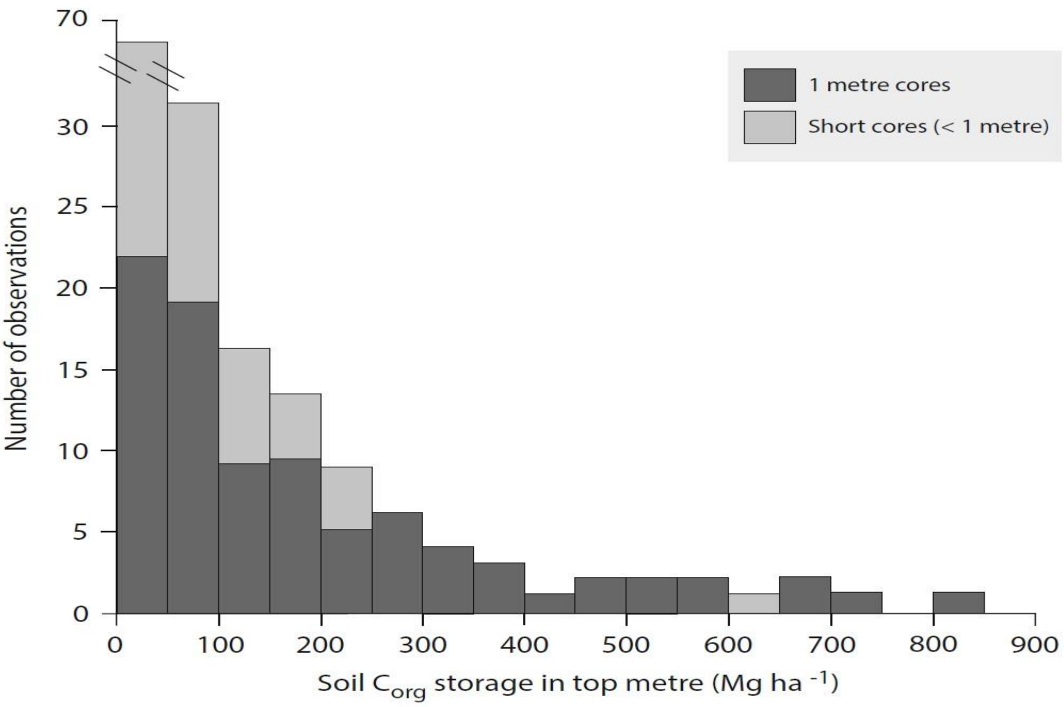

Figure 2-2 Soil Corg storage in seagrass in top meter (Mg/ha). Source: (Alongi, 2018)

Salt Marsh

Salt marshes is one of the blue carbon ecosystems studied in this thesis, and are intertidal wetlands that occur on low energy. Salt marshes consist of herbaceous flowering plants and small scrubs and can be found mostly on sheltered coastal areas and grow on slit and clay (mud) substrates. They represent an interface between terrestrial and marine ecotones, have inherited from many attributes from both and have some features that are unique (Adam, 2019)

Salt marshes can live on all continents except Antarctica, generally in temperate coastlines and in low latitudes. The global distribution of taxa illustrates that there are broad similarities between salt marshes in the Northern and Southern Hemisphere and indicate that major types of salt marshes can be related to latitude. Moreover, species richness of marsh grasses occur in high-latitude temperate zones (Alongi, 2018)

In relation to the dynamics of soil accretion of salt marsh, the accretion rates range from 2 to 10 mm /year with a median value of 5mm/year. Most of salt marsh accretion rates are between 1 and 7 mm/year. Sea-level is the ultimate arbitrator of salt marsh delineation, as considerable change in seal-level has ultimate impact on spatial and long-term distribution of salt marsh environment. There were considerable changes in the occurrence and extent of tidal marsh due to the position of seal-level, as it rose to its present position about six thousand years ago (Adam, 2016). Low- and mid-marsh zones can change rapidly because of changes in sediment that are caused by natural or anthropogenic process and that occur within decades or one to two centuries. However, upper march zones have the ability to remain stable for more than a millennium.

Two different measurements engage in carbon sequestration measurement of salt marsh. These measurements are soil accretion and rates. The rate of soil accumulation can be measured by a few methods such as radiotracers and numerical models. A common method to measure soil accretion rates is radiotracers which uses Pb and Cs radioisotope geochronology, involving the measurement of naturally occurring and artificial radionuclides with increasing sediment depth and deriving a slope (rate) from a simple model of decrease in radioisotope concentration with increasing depth. To do so, a sediment core is taken carefully from a given salt march area and sub sectioned to a depth of at least 100 cm which is preferred as surface sediments that mixed physically or biologically destroying the pattern of probable decrease in concentration (Alongi, 2018). The other common method to measure mass sediment accretion is the surface-elevation table or “RSET method”, which is relatively inexpensive, portable, and easy to measure.

Carbon sequestration rates in salt marshes are not correlated with changes in latitude Figure 2-3. Sequestration rates are rather a function of other factors such as the marsh age, marsh geomorphology, species composition, tidal inundation, tidal elevation, soil grain size, catchment and river input, ocean input and degree of human impact. The mean carbon sequestration rates values for salt marsh computed from 168 location are 212 ± 18 g Corg /m2 year. (Ouyang & Lee, 2014)has defined three factors that are the most important drivers of carbon sequestration rates in salt marshes. These factors are tidal range, and elevation.

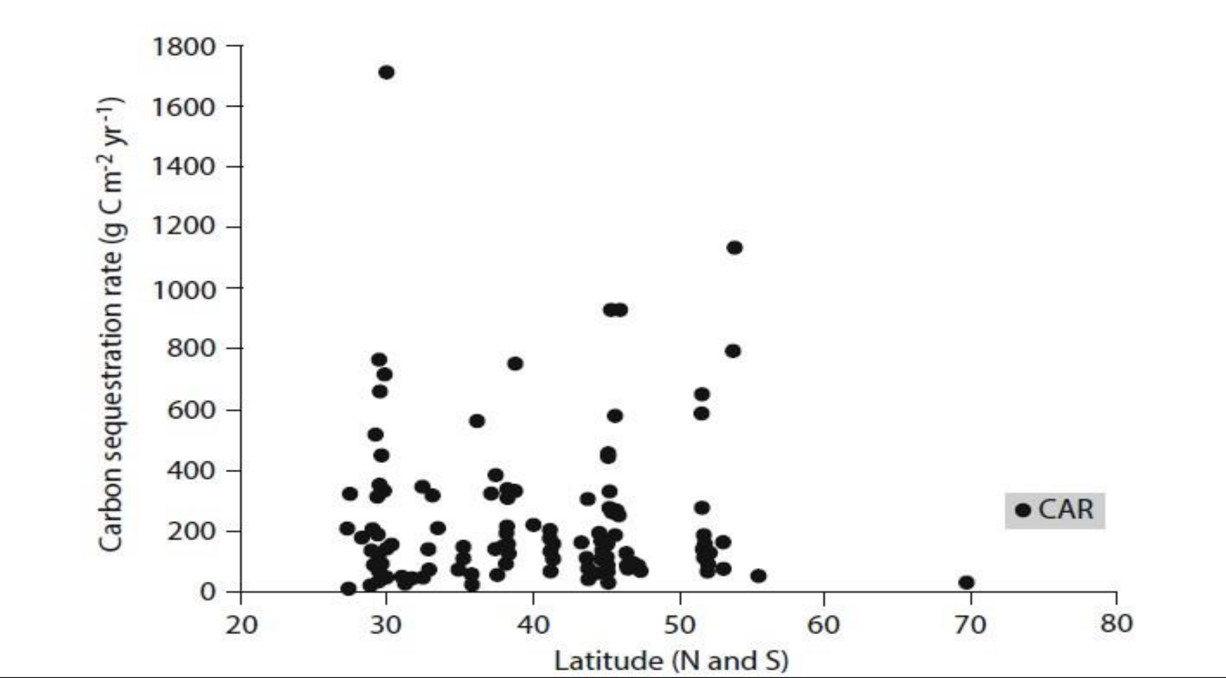

Figure 2-3 Rates of carbon sequestration in salt marshes as a function of latitude. Source: (Alongi DM, 2016)

According to the (Ouyang & Lee, 2014)the salt marshes that are in the North of latitude 68.4° have lower carbon accretion rates, whereas salt marshes that are located within the band of 48.4-58.4° N show the highest but very variable carbon accretion rates. This can be explained as reflecting a slower and shorter growing season of salt marsh at boreal latitude as well as a difference in the balance between rainfall and evaporation. Tidal range account for nearly 52% of the variation in carbon accretion rate whereas latitude accounts only for 29.6% of the variation.

By assuming that the total global area of salt marshes is equal to 41’657 km2(Ouyang & Lee, 2014), the total global sequestration rate is about 10 Tg Corg /year. The value of total soil carbon stock for the same area is equal to 1.2 Pg Corg (1’156 Tg Corg). On the other hand, the mean value for stock of soil carbon in salt marsh is 317.2 ± 19.1 Mg Corg /ha and the median value is 282.2 Mg Corg /ha. On average, around 92% of total carbon is vested below-ground in soil, which indicates that virtually all carbon stored in salt marshes is below-ground(Kennedy et al., 2014) .

Mature salt marshes that have been stable or pristine, or both, for a long time (usually centuries) have higher carbon storage capacity in comparison to the newly restored salt marshes such as those in river deltas in China(Artigas et al., 2015). In certain countries, to prevent tidal flooding and create suitable conditions for agriculture, salt marshes have been reclaimed, drained, and diked, thus carbon stocks in these type of salt marshes been deleted by disruption of upper soil layers where most of organic carbon occurs.

Globally, wetlands have lost significant amount of organic carbon, about 55 Pg for the World's soil. For instance, China has lost about 70 Pg organic carbon since 1970 due to the loss of large swaths of freshwater and estuarine marsh(Zheng et al., 2011). The situation is comparable in Japan and in other Asian countries where they converted wetlands to dry the land for agriculture purposes.

Salt marsh accretion can be affected by direct or indirect human activities. On example is in Cape Cod, Massachusetts, where indirect activities have made salt marshes lose significant amounts of soil and carbon over two centuries. Direct impact consists of habitat conversion, boating and dredging, while indirect impacts are for example eutrophication, die-off, oiling, and mosquito ditching (Alongi DM, 2016).

2.2.3 MapX

MapX is an online open-source application that was established in 2014 by UNEP/GRID-Geneva, aiming to support the sustainable use of natural resources and the environment by improving access to the best available geospatial information and related monitoring technologies(Lacroix et al., 2019). Currently, MapX is available in more than twenty languages, and it can access by low bandwidths Internet connectivity. MapX can harvest data through different existing standardized web services like Open Geospatial Consortium (OGC), Web map, feature and coverage services, and other APIs. Furthermore, MapX has different functionalities enabling users to visualize data in diverse ways. Data can be shown usnig proportional symbols and color ramps, they can be aggregated, or shown using advanced cartographic functions (e.g., bivariate legend), they can be overlaid with other data layers, time sliders can show the temporal aspects of the data, etc. Moreover, there is a separated informative environment in

MapX called dashboard that can be associated with a layer to complement and synthesize information shown on maps.

MapX provide different users access level such as public, member, and publisher or admin, for each user to have their own roles allowing them to read, publish, or edit contents. Users can access all public data but only download those that are authorized by its owner, based on the underlying license requirements of datasets. Data can be downloaded in various formats such as shapefile, GeoJSON, DXF, and SQLite.

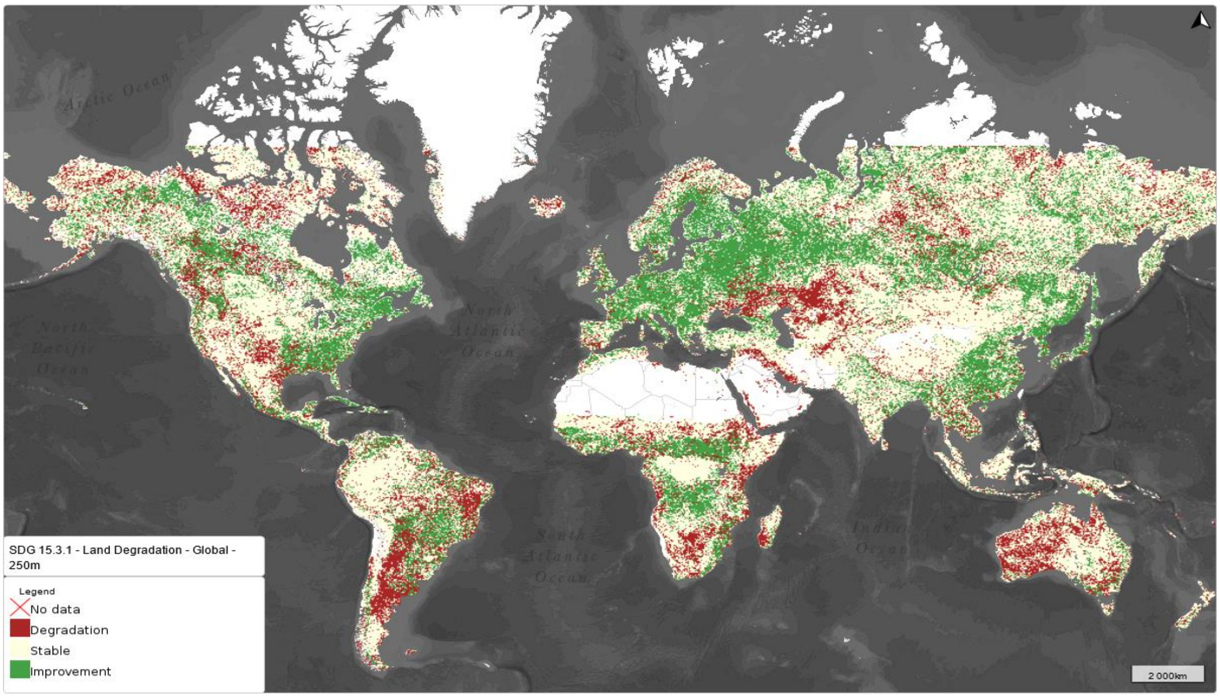

Figure 2-4 Status of land degraded improved at pixel level over the period 2001-2015. source: https://app.mapx.org/?project=MX-9ZY-VO1-EJM-388-I05&language=en&theme=classic_light

For the purpose of this thesis, MapX was used to publish geospatial data in a dedicated workspace, isolated from other MapX projects.

2.2.4 Apache Superset

Apache Superset is an open-source, modern, enterprise-ready business intelligence web application which can handle data at petabyte scale (big data). Superset provides different options for users to explore and visualize data in diverse ways. It provides:

- An intuitive interface for visualizing datasets and crafting interactive dashboards.

- A wide array of beautiful visualizations to showcase data.
- Code-free visualization builder to extract and present datasets.
- A world-class SQL IDE for preparing data for visualization, including a rich metadata browser.
- A lightweight semantic layer which empowers data analysts to quickly define custom dimensions and metrics.
- Out-of-the-box support for most SQL-speaking databases.
- An extensible security model that allows configuration of very intricate rules on who can access which product features and datasets.
- Integration with major authentication backends (database, OpenID, LDAP, OAuth, REMOTE_USER, etc.).
- The ability to add custom visualization plugins.
- An API for programmatic customization.
- A cloud-native architecture designed from the ground up for scale.

Superset is cloud-native and flexible in terms of choosing different web server (Gunicorn, Nginx, Apache), metadata database engine (MySQL, Postgres, MariaDB, etc.), message queue (Redis, RabbitMQ, SQS), results backend (S3, Redis, Memchached), and caching layer such as Memchached, Redis, etc. (Dev, n.d.).

For the purpose of this thesis, Apache Superset was used to publish statistical data.

Chapter 3 Results

This section illustrates the outcomes of the work that has been done in MapX and Apache Superset. A workspace with 11 views were created and 33 views were imported from different workspace in MapX to show the blue carbon ecosystems key figures, and a dashboard was created in Apache Superset to evaluate different parameters related to blue carbon ecosystems.

3.1 Publication of geospatial layers in MapX

To illustrate the blue carbon ecosystems key figures (carbon stocks and fluxes), 11 geospatial layers were created for each blue carbon ecosystem under the "Valuing blue carbon stocks for a sustainable future" workspace. In addition to this, 33 geospatial layers from different workspaces related the blue carbon ecosystems were shared under the classification of Carbon, Land, Human Drivers, Marine and Coastal, and Climate into this workspace. The URL of the workspace in MapX is https://app.mapx.org/?project=MX-9ZY-VO1-EJM-388-I05&language=en (private as for now).

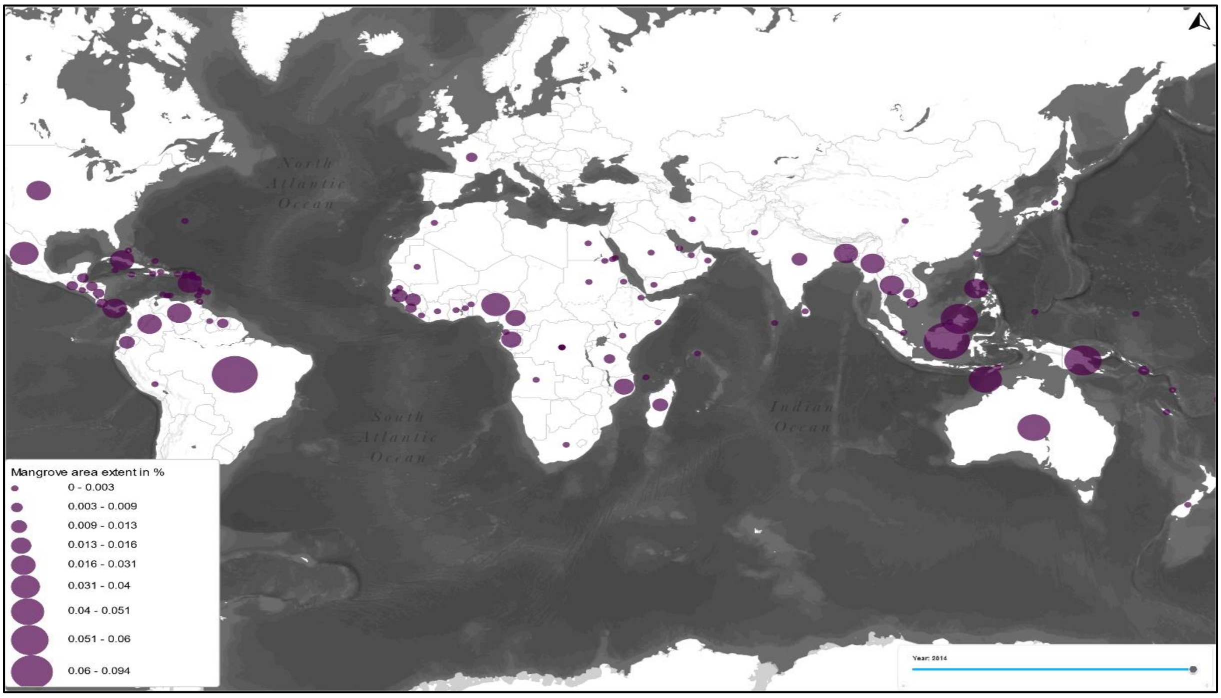

Figure 3-1 *Mangrove area extent, year 2000-2014.*

Source https://app.mapx.org/static.html?language=en&views=MX-0Q3YP-8HORF-CLL6M&zoomToViews=true&p=0&b=0&z=0.887&lat=0&lng=0&t3d=false&sat=false&theme=classic_light

3.1.1 Mangrove

To determine the carbon stocks and fluxes related to the mangrove, six layers were created in MapX. Based on data that was collected for mangroves biome status between 2000 and 2014, a layer with a time slider function was created. Figure 3-2shows the mangrove area extent in km2 as well as in percentage across the globe. Time slider function in MapX was used to show the mangrove extent changes between 2000 and 2014. Two different views were created, one for the area extent in km2 and one for the area extent in %, classified in 10 and 5 groups, respectively. The size of each circle corresponds to the percentage values of each country's mangrove extent.

On the Figure 3-2, Australia, Indonesia, Brazil, Malaysia, and Papua New Guinea have the largest circle in comparison to the other countries. Country polygons with dark green colors correspond to important areas of mangrove extent, e.g., Australia, Brazil, Myamar, Indonesia, Malaysia, Mexico, and Thailand. Inversely, light green corresponds to countries with as small area of mangrove forest, e.g., in North America, Europe and Asia (except Southeast Asia).

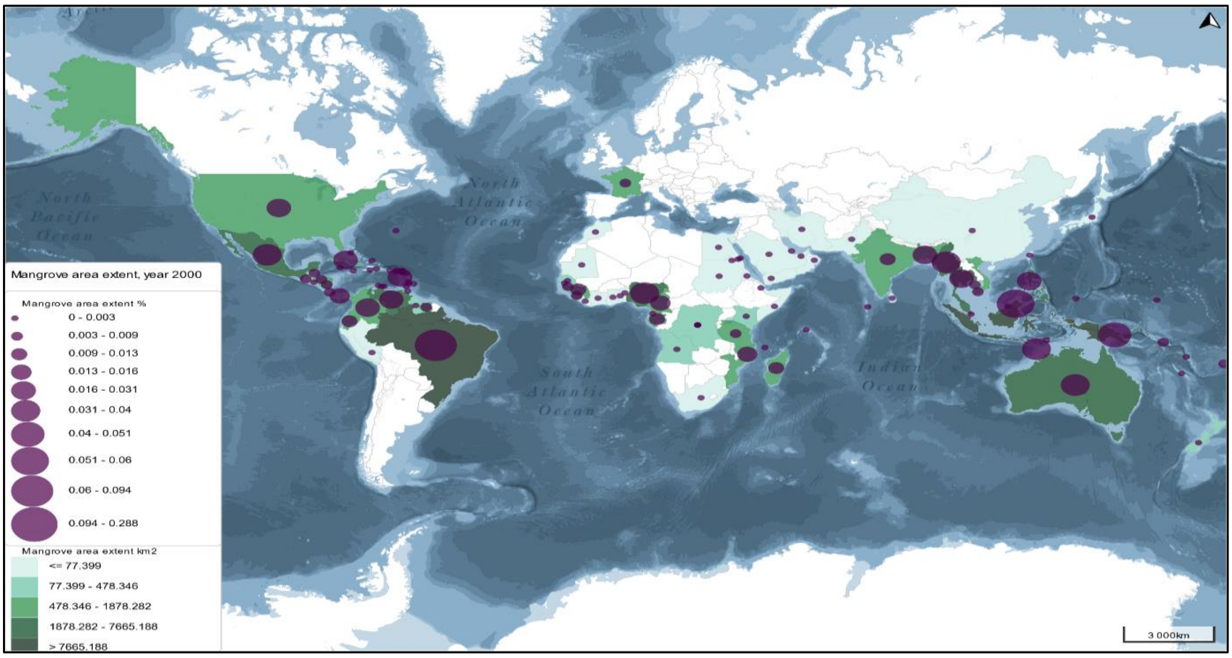

Figure 3-2 Mangrove area extent in km2 and % in the year 2000.

Source : https://app.mapx.org/static.html?language=en&views=MX-0Q3YP-8HORF-CLL6M%2CMX-0T9XV-HUTHP-1Y9YG&zoomToViews=true&p=0&b=0&z=0.887&lat=0&lng=0&t3d=false&sat=false&theme=classic_ligh

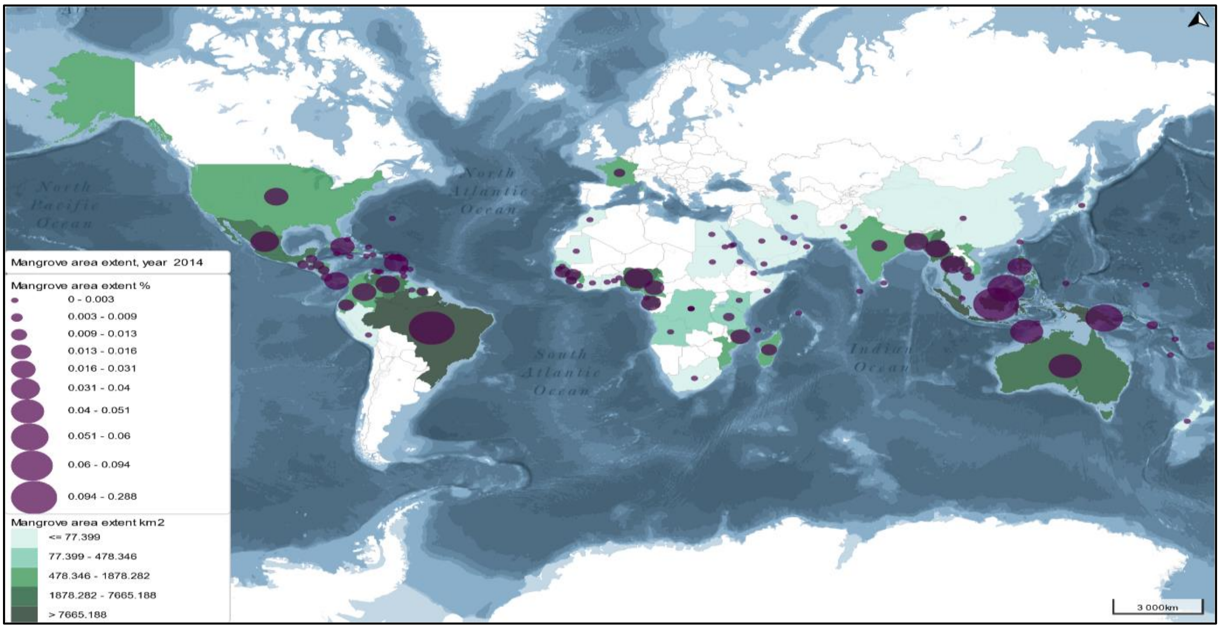

Figure 3-3 Mangrove area extent in km2 and %, in the year of 2014. Source:https://app.mapx.org/static.html?language=en&views=MX-0Q3YP-8HORF-CLL6M%2CMX-0T9XV-HUTHP-1Y9YG&zoomToViews=true&p=0&b=0&z=0.887&lat=0&lng=0&t3d=false&sat=false&theme=classic_ligh

Figure 3-3shows the global mangrove extent in the year 2014. For those who would like to navigate through time the URLs of those layers are: https://app.mapx.org/static.html?language=en&views=MX-0Q3YP-8HORF-CLL6M%2CMX-0T9XV-HUTHP-1Y9YG&zoomToViews=true&p=0&b=0&z=0.887&lat=0&lng=0&t3d=false&sat=false&theme=classic_light .

For instance, there is changes in mangrove area extent in % for Indonesia, Myanmar, and Bangladesh. To show mangrove depth distribution over the globe, a specific layer was created into MapX. The dept of mangrove is classified into five categories and represented with green colors. The dark nature of the colors corresponds to the depth, meaning that dark color corresponds to the higher depth.

According to the figure 3.1.1-3, most of the mangroves with high depths (2.49 – 4 m) are located in the Caribbean region and the Eastern part of Asia (Indonesia, Malaysia, Thailand, Bangladesh, Myanmar, and the Philippines). However, some countries in Africa such as Gabon, Angola, Mozambique, Madagascar, and Kenya have a mangrove depth around 4m.

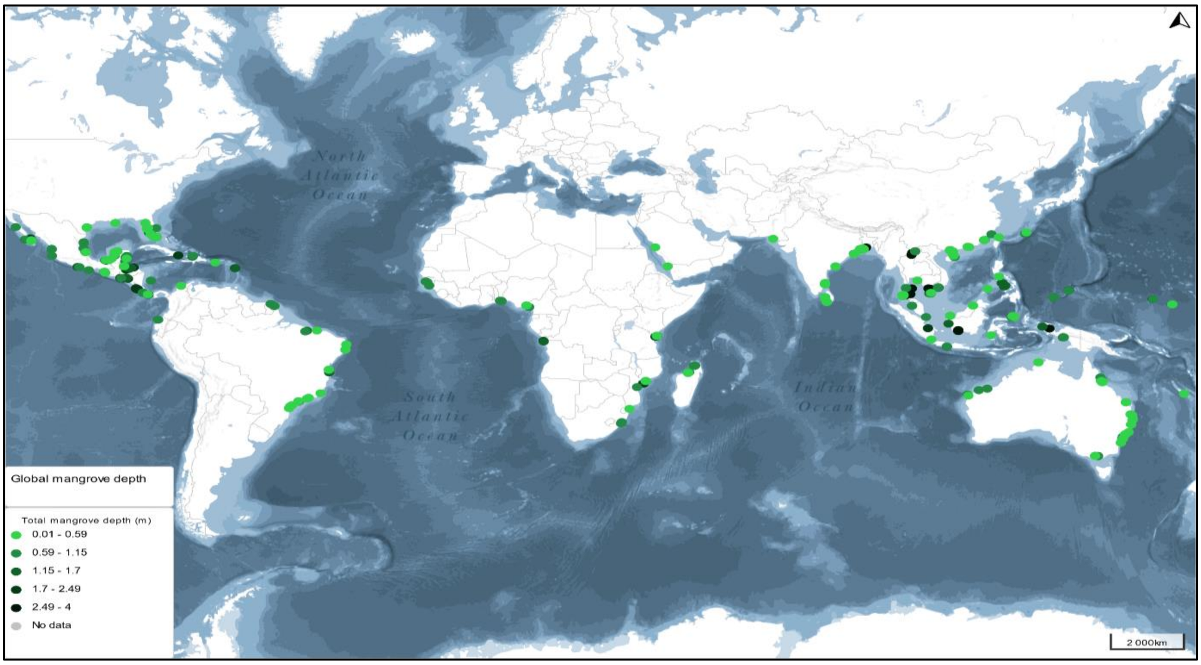

Figure 3-4 Global mangrove depth in meter.

Source: https://app.mapx.org/static.html?language=en&views=MX-S5XG0-6GCMS-MES5O&zoomToViews=true&p=0&b=0&z=0.887&lat=0&lng=0&t3d=false&sat=false&theme=classic_ligh

In relation to hydromorphology of mangrove, a layer was created, indicating the habitats where mangrove grow up. There are mainly three types of habitats such as riverine, estuarine, marine environments. These habitats have specific characteristics, for instance, riverine refers to areas that are contained within a channel (e.g., river, creek, or waterway). Estuarine refers to areas where rivers meet the ocean or another large body of water. In other words, it is a mixture of fresh water draining from the land and salty seawater. In Figure 3-5, other types of hydromorphology combining riverine (red color), marine (orange color), and estuarine (green color) are represented. These are called estuarine/marine (brown color) and estuarine/riverine (yellow color).

In Figure 3-5 Hydromorphology of mangrove.shows the habitat the most represented for mangroves is riverine whereas smaller areas of mangroves grow in estuarine/marine environments. Indonesia is incredibly unique in terms of mangrove hydromorphology as all the types of mangrove habitats are present.

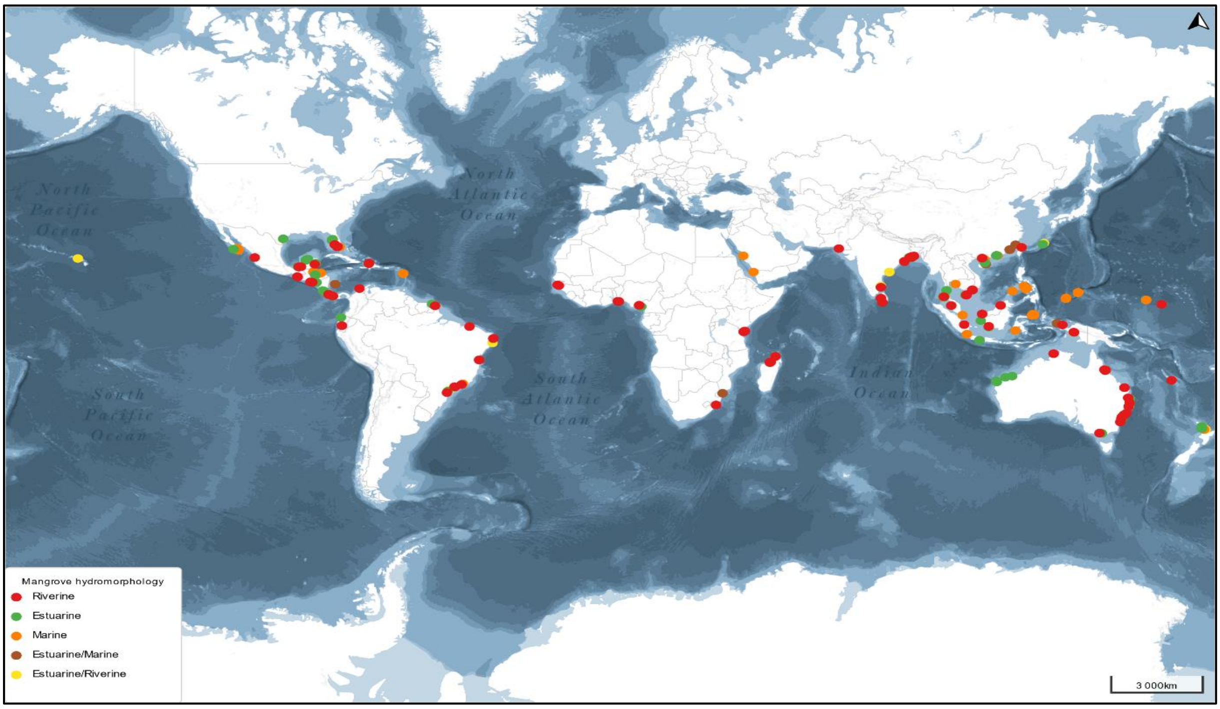

Figure 3-5 Hydromorphology of mangrove.

source: https://app.mapx.org/static.html?language=en&views=MX-114MJ-DFJ6G-45OIJ&zoomToViews=true&p=0&b=0&z=0.887&lat=0&lng=0&t3d=false&sat=false&theme=classic_light

3.1.2 **Seagrass**

Although there is not enough data for seagrass to represent its status globally, three layers were created in MapX to show carbon stock and fluxes. These three layers illustrate seagrass above ground and below ground carbon stock rates as well as seagrass carbon sequestration rates. The seagrass carbon stock rate varies in space and relates to mangroves' habitat. Seagrass mostly grow in extraordinarily complex ecosystems rather than in isolation, they are relatively stable in tropics area and have broad interannual variations in temperate regions.

Figure 3-6 represents the global distribution of seagrass which composed of two subsets of points and polygons occurrence of data that imported from WESER Biodiversity workspace.

Most of the seagrass data are based on site specific studies thus there is not enough data regionally or globally. However, the data representing carbon sequestration rates data were compiled and published into MapX.

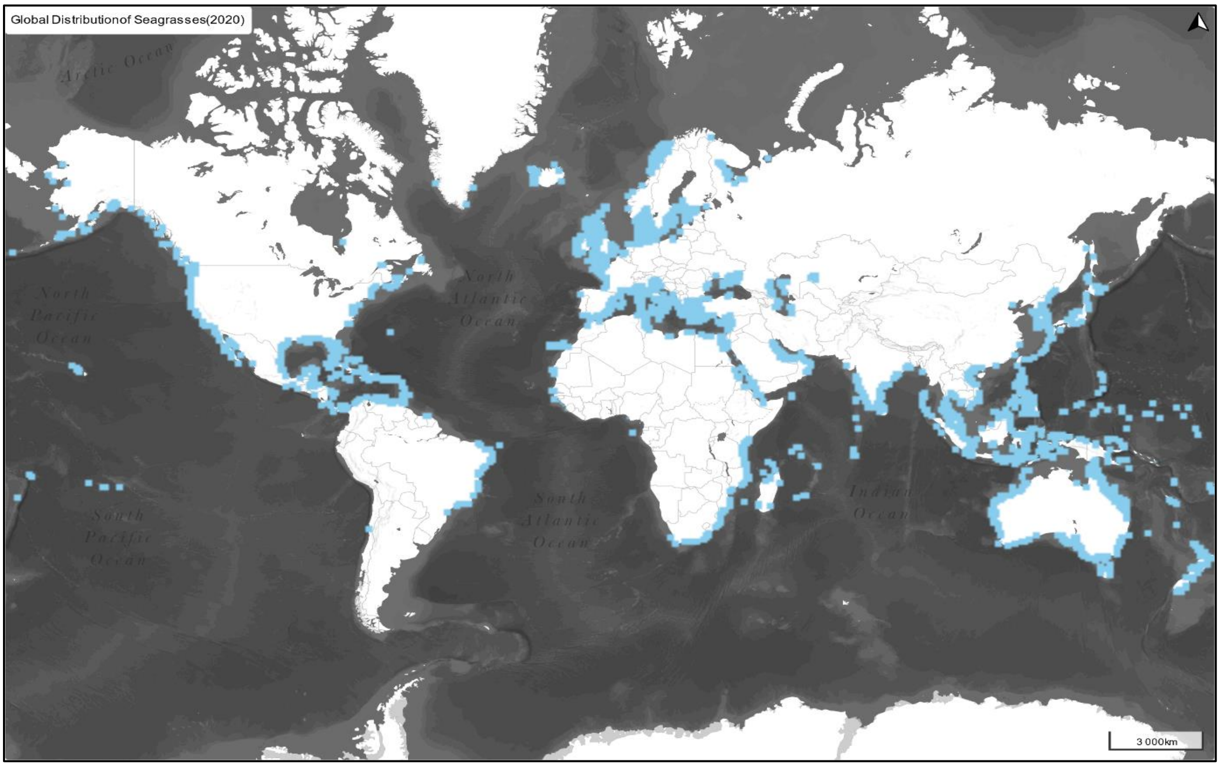

Figure 3-6 Global distribution of seagrass.

source: https://app.mapx.org/static.html?language=en&views=MX-THC63-08B5L-G63S0&zoomToViews=true&p=0&b=0&z=0.887&lat=0&lng=0&t3d=false&sat=false&theme=classic_light

Figure 3-7. More specifically, the layer was separated into three views . The following URLs are belong to the these views:

North & Central America : https://app.mapx.org/static.html?language=en&views=MX-X58OA-FPOAM-L2KVA&zoomToViews=false&p=0&b=0&z=3.131&lat=28.585&lng=-96.526&t3d=false&sat=false&theme=classic_light

Europa: https://app.mapx.org/static.html?language=en&views=MX-X58OA-FPOAM-L2KVA&zoomTo-Views=false&p=0&b=0&z=3.131&lat=51.625&lng=6.55&t3d=false&sat=false&theme=water_light

Asia: https://app.mapx.org/static.html?language=en&views=MX-X58OA-FPOAM-L2KVA&zoomToViews=false&p=0&b=0&z=3.036&lat=3.247&lng=93.843&t3d=false&sat=false&theme=water_light

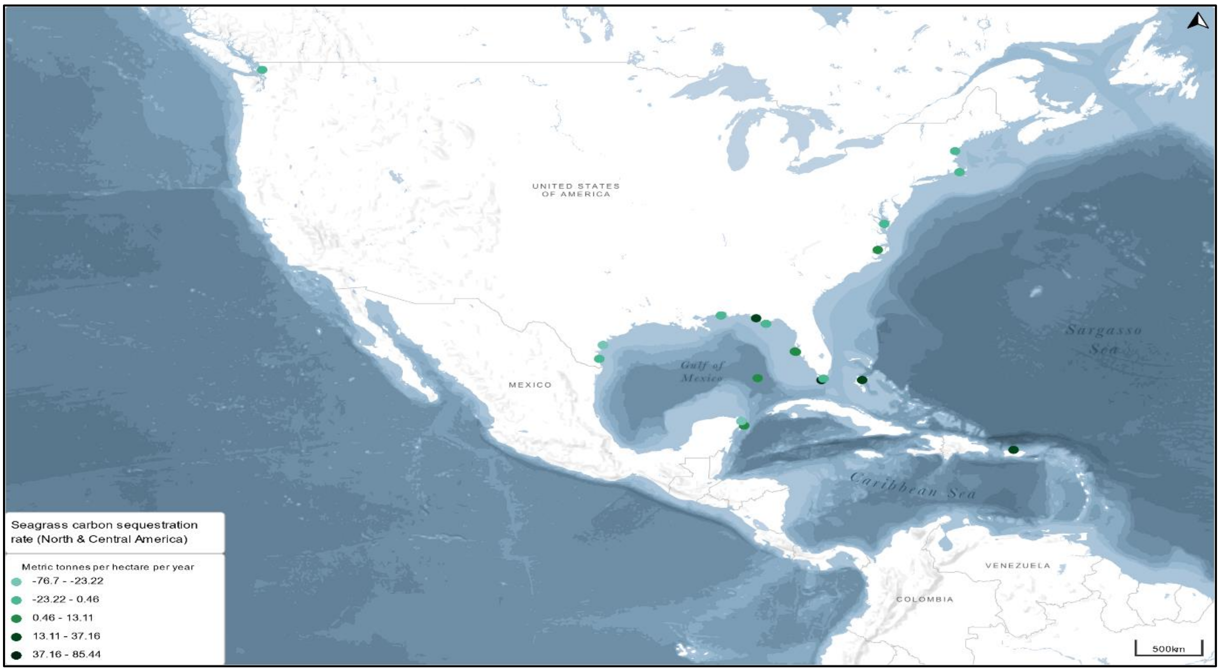

Figure 3-7 Seagrass carbon sequestration rate for North and Central America.

source: https://app.mapx.org/static.html?language=en&views=MX-X58OA-FPOAM-L2KVA&zoomToViews=false&p=0&b=0&z=3.131&lat=28.585&lng=-96.526&t3d=false&sat=false&theme=classic_light

The rates are varied depending to the region. For Central America (which is a tropical region) the sequestration rate is between 37.16 and 85.44 metric tons per hectare and per year, whereas in Canada the sequestration rate could be minus (-76.7 up to -23.22 Ton/h year).

In Denmark and Sweden there is a variation in temperature during the season, the seagrass carbon sequestration rate is small, – 0.02 up to 1.6 tons CO_2/h/year for Sweden, and -0.18.9 up to 29.79 tons CO_2/h/year for Denmark.

For South and Southwest Europe, the rate is positive and represented on Figure 3-8 by a dark green color. For Spain, the rate is different across provinces. It ranges between 1.21- and 27.38-tons CO_2/h/year. Meanwhile, the rate for Portugal is between -3.2- and 11.32-tons CO_2/h/year. The rate for Germany equals to 1.21, Netherlands = 1.87, France = 3.44, Italy = 2, and Greece between 4.35- and 10.26-tons CO_2 per hectare per year.

In contrast to Europe and America, Asia has the highest carbon sequestration rate. For instance, the sequestration rate for India and Philippines is 77.82 and 22.53-tons CO_2/h/year, respectively. The sequestration rate for Australia ranges from -2.68 to 22.77-tons CO_2/h/year.

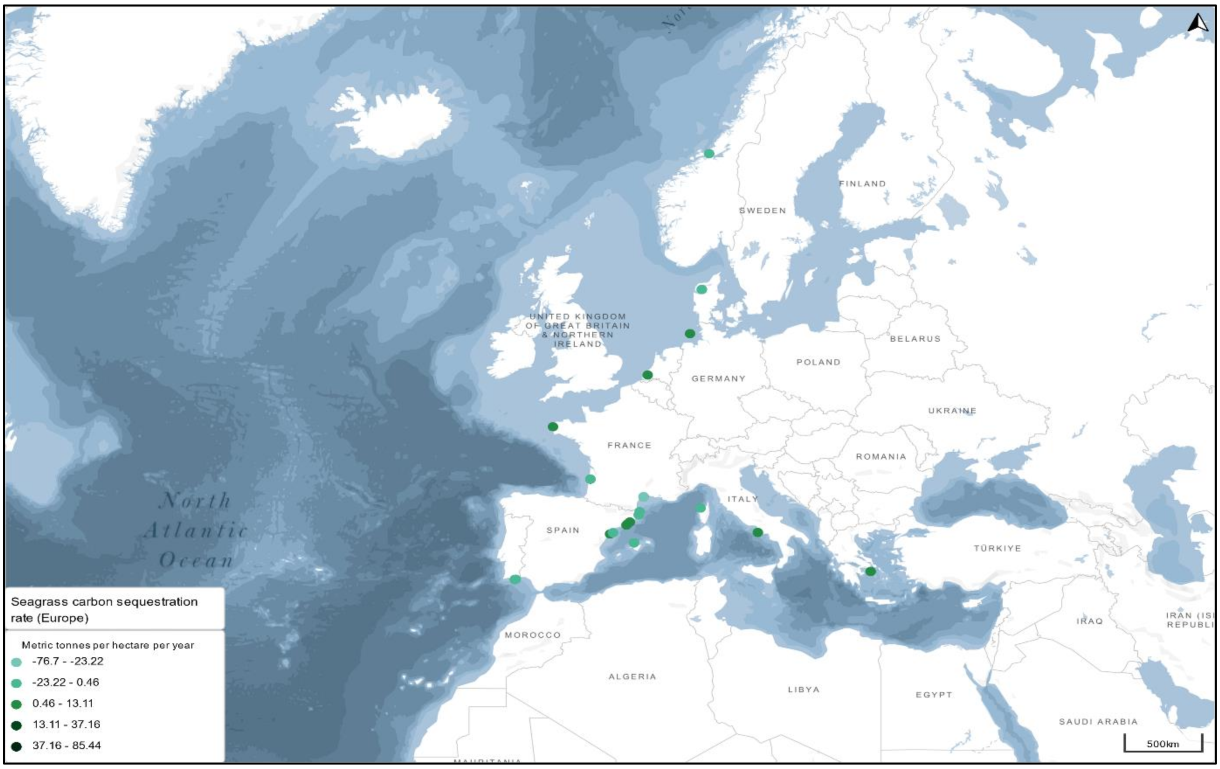

Figure 3-8 Carbon sequestration rate for Europe region.

Source: https://app.mapx.org/static.html?language=en&views=MX-X58OA-FPOAM-L2KVA&zoomTo-Views=false&p=0&b=0&z=3.131&lat=51.625&lng=6.55&t3d=false&sat=false&theme=water_lig

In terms of global seagrass carbon stock rate, two different layers were created to represent seagrass below ground and seagrass above ground carbon stock rates globally. The stock rates vary depending on the region. Below ground, it ranges from 0.034 to 3’076 g/m2, while above-ground it is between 0.001 to 1’509.2g/m2.

Few regions in the World show high carbon stock rates. These regions are Island of Menorca, Spain with 3’076 g/m2, Otranto, Italy with 1’793.48, Guam island with 3’037 g/m2, Melbourne, Australia with 2’006 g/m2, Mvuleni, Kenya with 1’683 g/m2, and Playa del Carmen, Mexico with 2’846.4 g/m2.

Figure 3-9 shows that high carbon stock rates for seagrass above ground (e.g., above 600 g/m2) can be found in all continents except Antarctica. However, most of the seagrass samples that were collected across the globe, indicate 0.001 to 45.719 g/m2 carbon stock rates.

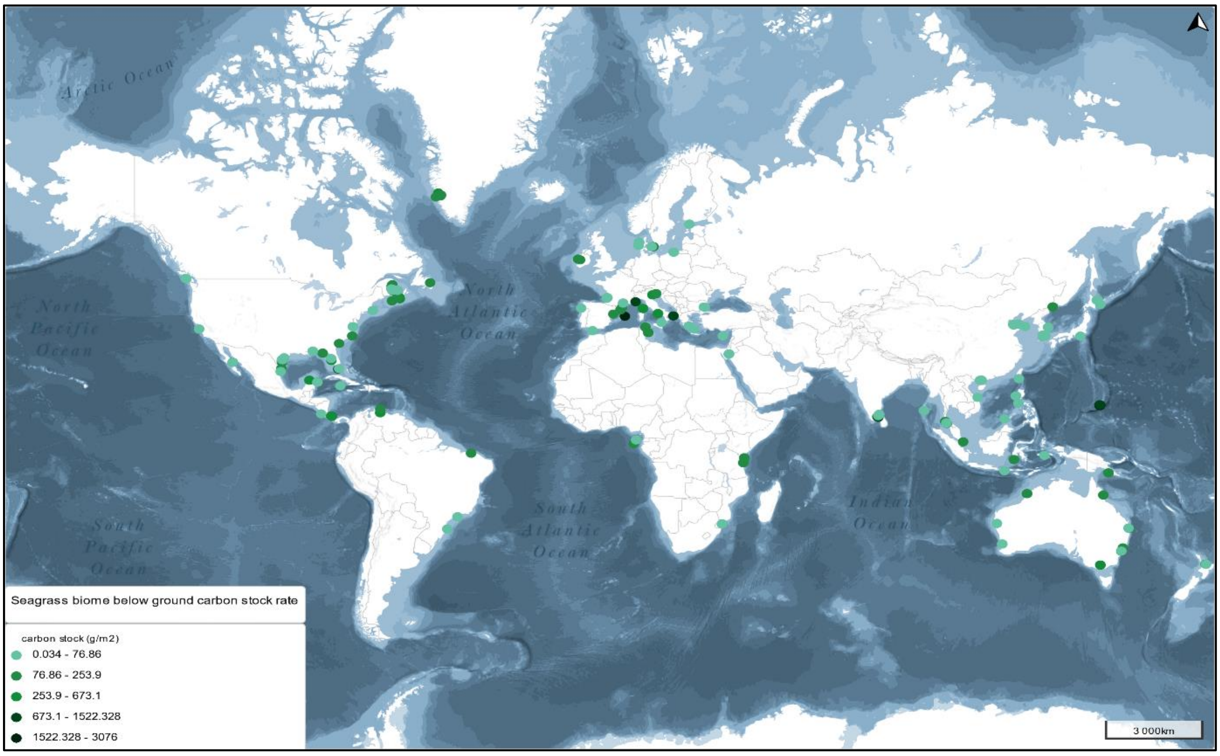

Figure 3-9 Seagrass biome above ground carbon stock rate.

Source : https://app.mapx.org/static.html?language=en&views=MX-N2MZ4-PEZWF-KHFMW&zoomToViews=true&p=0&b=0&z=1.288&lat=38.839&lng=-37.507&t3d=false&sat=false&theme=water_ligh

3.1.3 Salt Marsh

Duo to a lack of studies and data for salt marshes, only two layers were created in MapX. They show salt marsh carbon sequestration rates and salt marsh storage. The first layer has data only on Canada, America, and some parts of Europe such as England, France, and the Netherlands. The carbon sequestration rate for salt marsh is between 0.66 and 68.57 metric tons per hectare per year.

Based on Figure 3.1.3-1, the Netherlands has one of the highest carbon sequestration rates with 68.57 tons CO_2/h/year. and Sabine National Wildlife Saint Martins, Bay of Fundy, Canada Refuge, Louisiana, USA are among the regions holding the highest carbon sequestration rate with 34.03 and 68.82tons CO_2/h/y, respectively.

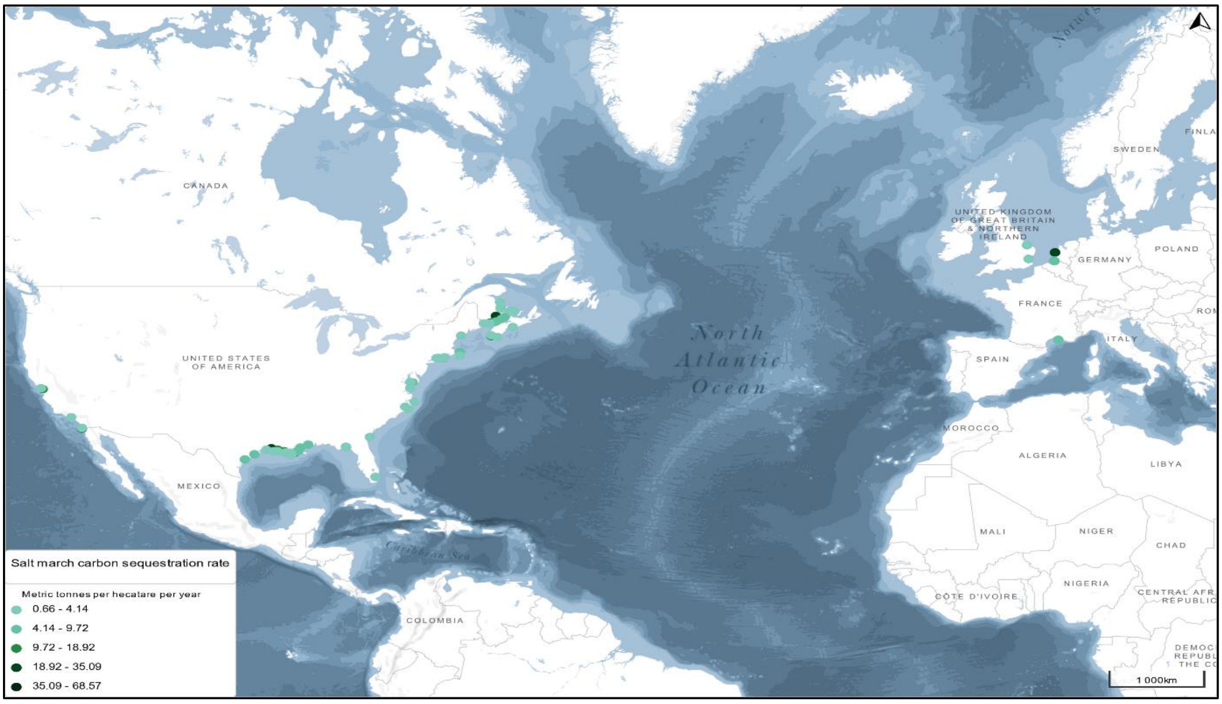

Figure 3-10 Salt marsh carbon sequestration rate. source:https://app.mapx.org/static.html?language=en&views=MX-70MR9-N572X-J9DGE&zoomToViews=true&p=0&b=0&z=1.288&lat=38.839&lng=-37.507&t3d=false&sat=false&theme=water_light

3.2 Development of a dashboard in Apache Superset

A dashboard was developed in Apache Superset, illustrating the data related to mangroves. This dashboard consists of two parts: (1) at the global scale, and (2) at country level, allowing to apply filters in order to show the data for a specific country. The URL of the dashboard is: https://dash-staging.unepgrid.ch/superset/dashboard/259/?native_fil-ters_key=iNa2faMCl04F0EeMLZVpNJNpF43GboIsOoeqtI0lLr6iK469BTWrWQXymgLXJ7iT

Six different charts (such as pie charts and big number trends charts) were created to show mangrove and biome coverages globally. The data represent areas and percentages of changes in extent areas between years 2000 and 2014.

Figure 3.2-1 illustrate the global mangrove forest cover which is equal to 81’574.7 km2 for year 2014. It also shows the percentage of change in mangrove cover between 2000 and 2014: -2.3 % (1’876.22 km2) globally. Biome has experienced a higher change (nearly twice as man-grove) in forest cover percentage between 2000 and 2014.

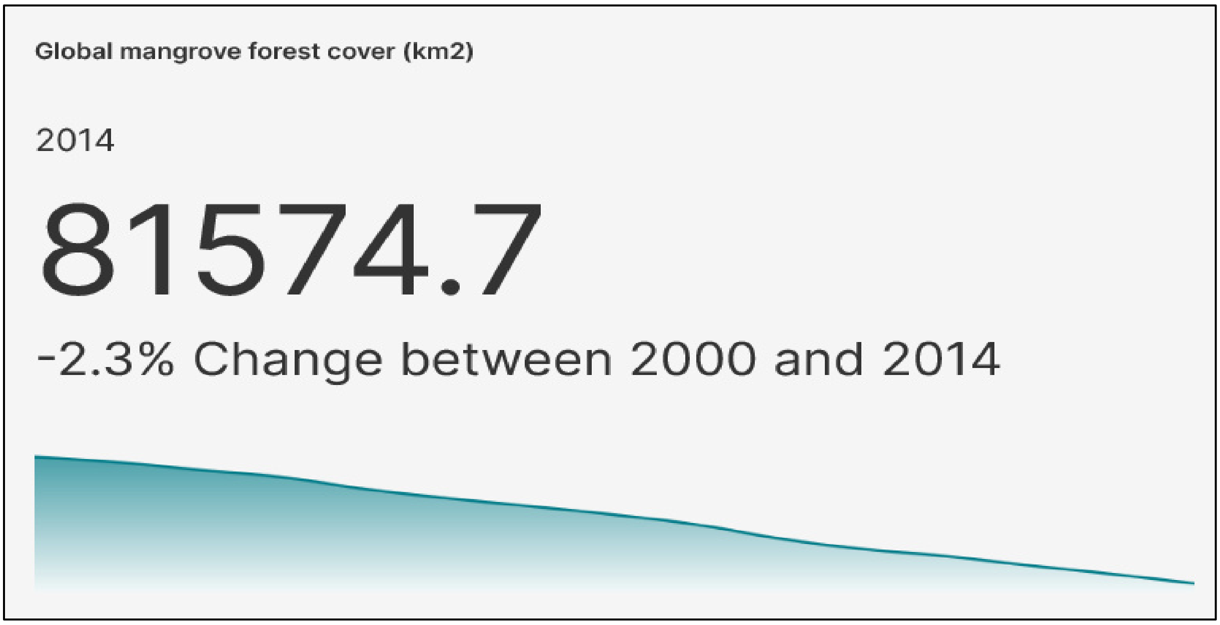

Figure 3-11 Global mangrove forest cover trend

The change for biome is -5.1 %, which corresponds to 8’377.7 km2. Furthermore, the biome forest cover for year 2014 is 164’265 km2.

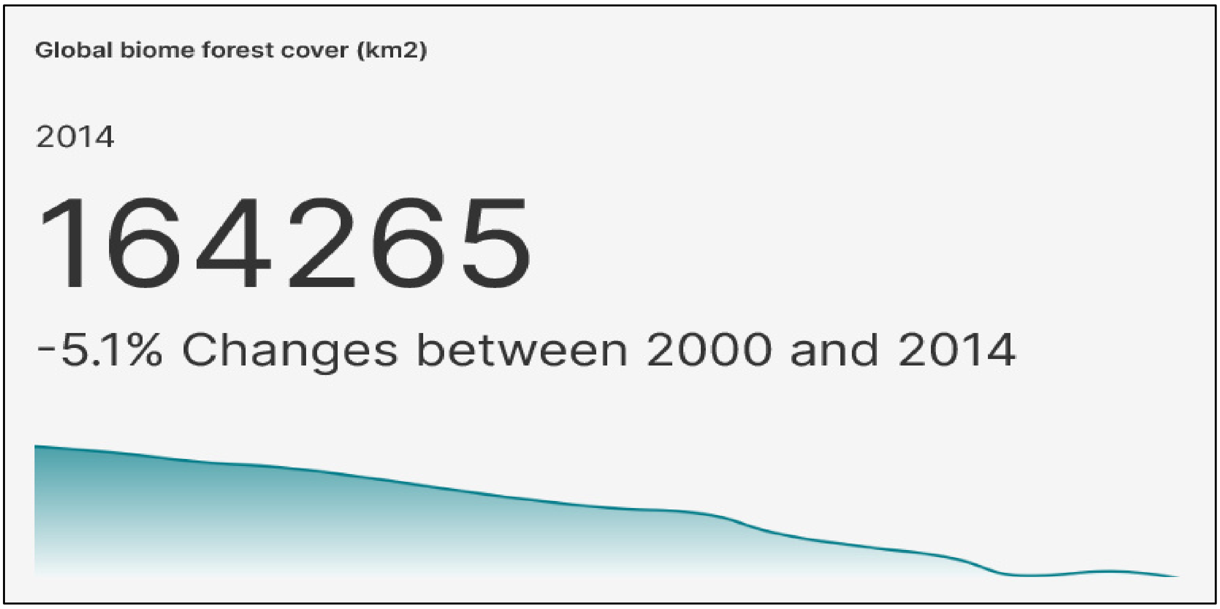

Figure 3-12 Global biome forest cover trend

On Figure 3-13, it can be seen that five countries (namely, Indonesia, Brazil, Malaysia, Papua New Guinea, and Australia) accounted for more than 50 % mangrove and biome forests in the World in 2000.

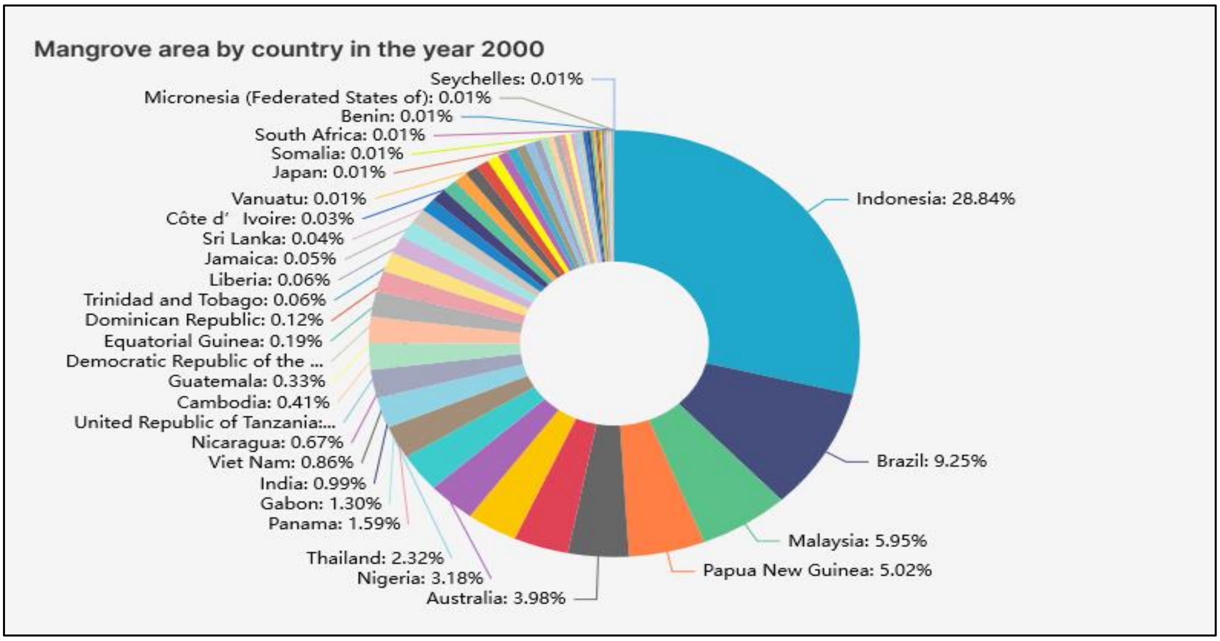

Figure 3-13 Mangrove area by country in the year 2000

These countries have experienced the highest changes in mangrove and biome in terms of their area extent. Indonesia has the biggest mangrove forest cover with 28.84 %. This percentage for Brazil is 9.25%, for Malaysia 5.95 %, Papua New Guinea 5.02 %, and Australia 3.98 %. However, due to the climate change and anthropogenic activities, there was a decline in percentage of mangrove forest cover between 2000 and 2014.

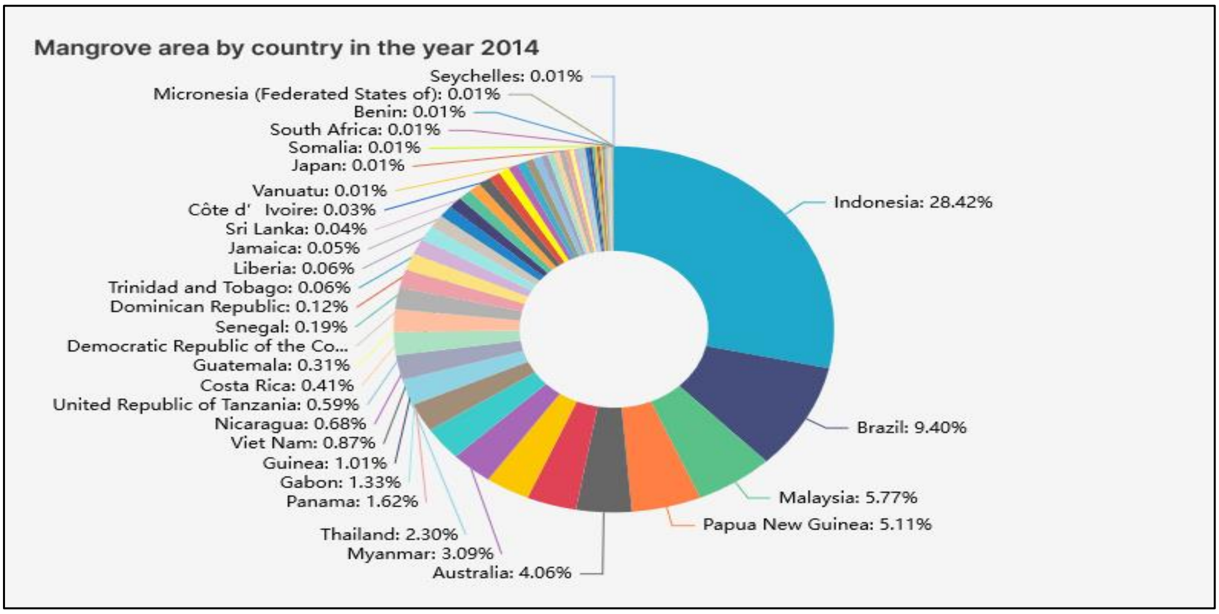

Figure 3-14 Mangrove area by country in the year 2014.

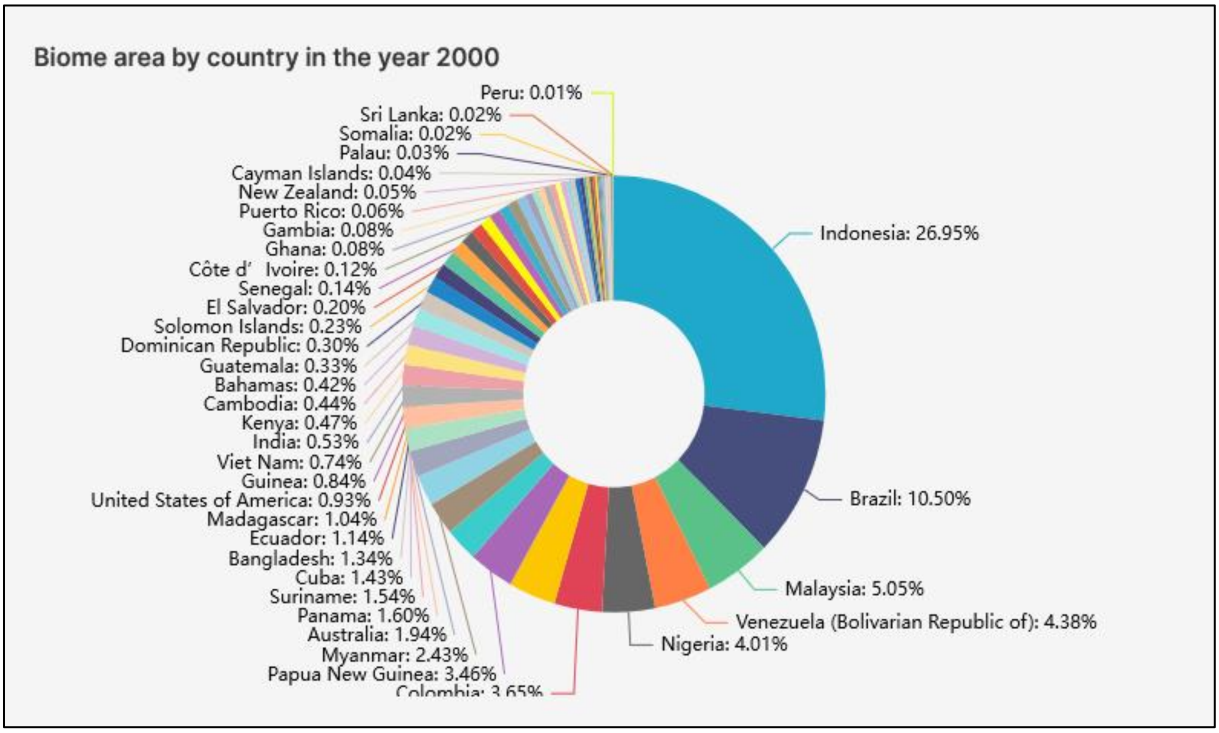

Figure 3-15 Biome area by country in the year 2000.

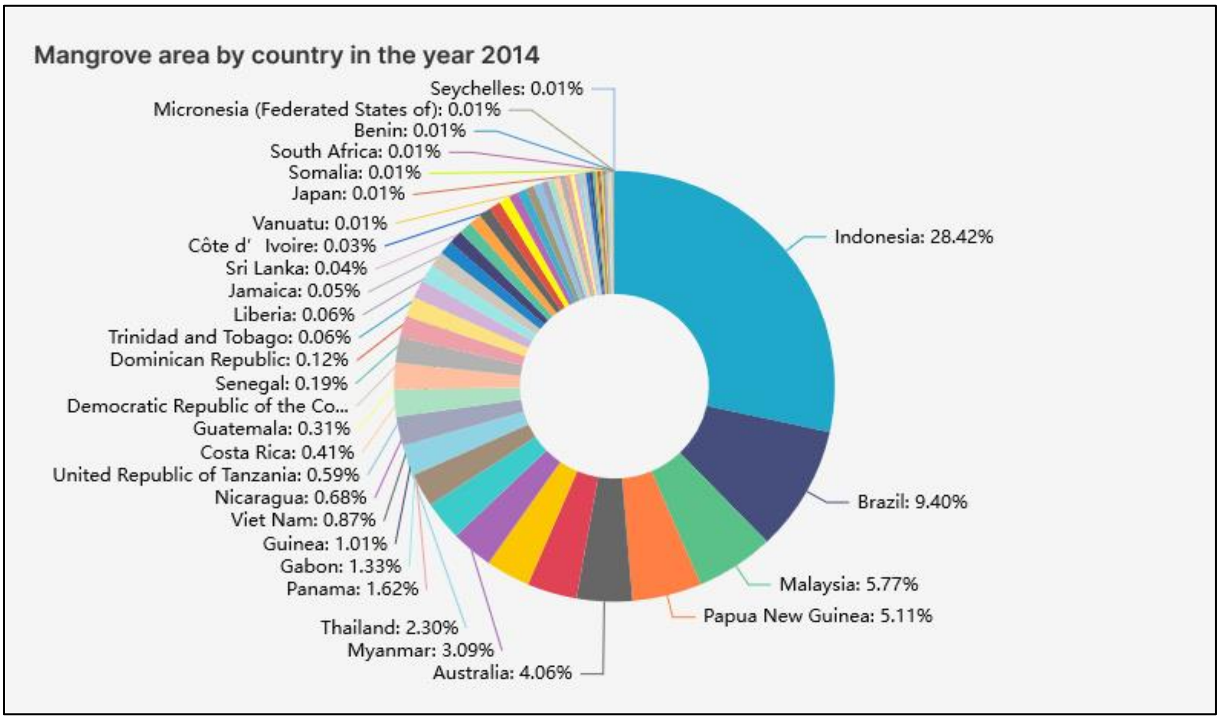

Figure 3-16 Biome area by country in the year 2014.

3.3 Well known platforms specific to blue carbon

A list of platforms on marine ecosystems is available below, in Table 1. Some of those platforms provide web services, hence they are interoperable with other platforms like MapX, but for some of them it is required to download the data and republish it every time one wants to publish them online. Form this we can conclude that more interoperability is needed. Moreover, those platforms are not all specific to blue carbon. From this we can conclude that the development of a knowledge platform on blue carbon would fill an important gap.

Table 1: List of platforms on marine ecosystems.

Name	URL	Coverage	feasibility
Resource watch	https://resourcewatch.org/data/explore	Global	Varying but general good
Nasa Earth Observations	https://neo.gsfc.nasa.gov/view.php?datasetId=MOD_LSTD_M Data explorer : https://go.nasa.gov/3I2UDJz	Global	Would be high if service work fine
Esri Open Data Hub	https://hub.arcgis.com/search	Global	Very good
Natural Earth	http://www.naturalearthdata.com/downloads/	Global	Good
Pangea	https://www.pangaea.de/	Global	Very good
Harvard Dataverse	https://dataverse.harvard.edu/	Global	Very good
UNEP Environmental Data Explorer	https://www.unep.org/publications-data	Global	Good
Global Mangrove Watch	https://www.globalmangrovewatch.org/	Global	Very good
The Partnership Platform	https://sdgs.un.org/partnerships/browse	Global	Good

Chapter 4 Interpretation and Discussion

Blue carbon ecosystems are some the world's most efficient carbon sinks ecosystems, living in coastal areas and having favored carbon accumulation in soils for millennia. However, they are extremely sensitive to climate change and anthropogenic activities. Numerous human activities adversely affect blue carbon ecosystems. These activities are known as human disturbances and have caused damages on blue carbon ecosystems in terms of distribution, growing, sequestration, and storage.

Based on the literature review, the MapX layers and the Apache Superset dashboard human disturbances can be summarized as follows:

- Conversion of blue carbon ecosystems to agriculture land.
- Sedimentation, hydrological properties changes, and erosion.
- Pollution and land exploitation.
- Industrial logging.

For instance, agriculture and conversion of land to aquaculture is the most predominant human activity that cause significant losses of mangrove in Asia (e.g., Myanmar, Thailand, Indonesia, Bangladesh, and Sri Lanka). Industrial logging occurs in Malaysia and Indonesia.

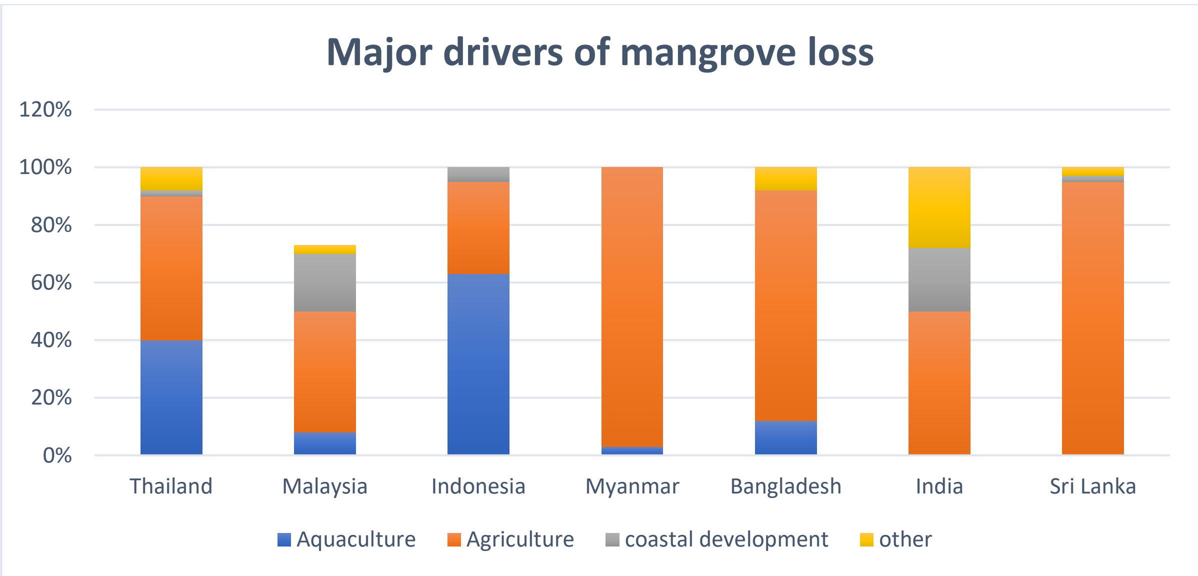

Figure 4-1 Major drivers of mangrove loss, modified from Giri et al, 2011

Based on the above chart, it can be seen that agriculture activities have a massive impact on mangrove loss in Myanmar: around 97 %. Figure 4-2we see that Myanmar has experienced the highest changes in mangrove and biome extent between 2000 and 2014.

Figure 4-2 Myanmar mangrove and biome extent between 2000 - 2014

Furthermore, industrial logging also caused mangrove loss in countries like Malaysia and Indonesia. For countries like Papua New Guinea, Indonesia, and North Australia, sedimentation and hydrological properties changes, and erosion count as major contributors to mangrove loss.

In South America, beside the abovementioned human disturbances, shrimp- and fishing-industries are the main contributors to mangrove loss. For instance, in Ecuador, the main reason behind mangrove loss is shrimp industry. For Honduras, 12 % of mangrove loss between 1985 and 2013 is related to shrimp farming, and in Guyana transformation of mangrove coastal land to agriculture and aquaculture are the mains source of mangrove loss. **Error! Reference source not found.** illustrates Honduras mangrove and biome extent between 2000 and 2014. Overall, there was a 6 % change between 2000 and 2014 and the annual change was -4.712 %. For the African continent, the main hotspots of mangrove loss apart from agriculture are water pollution, land exploitation, construction of dams, salt ponds, coastal development, and oil industry.

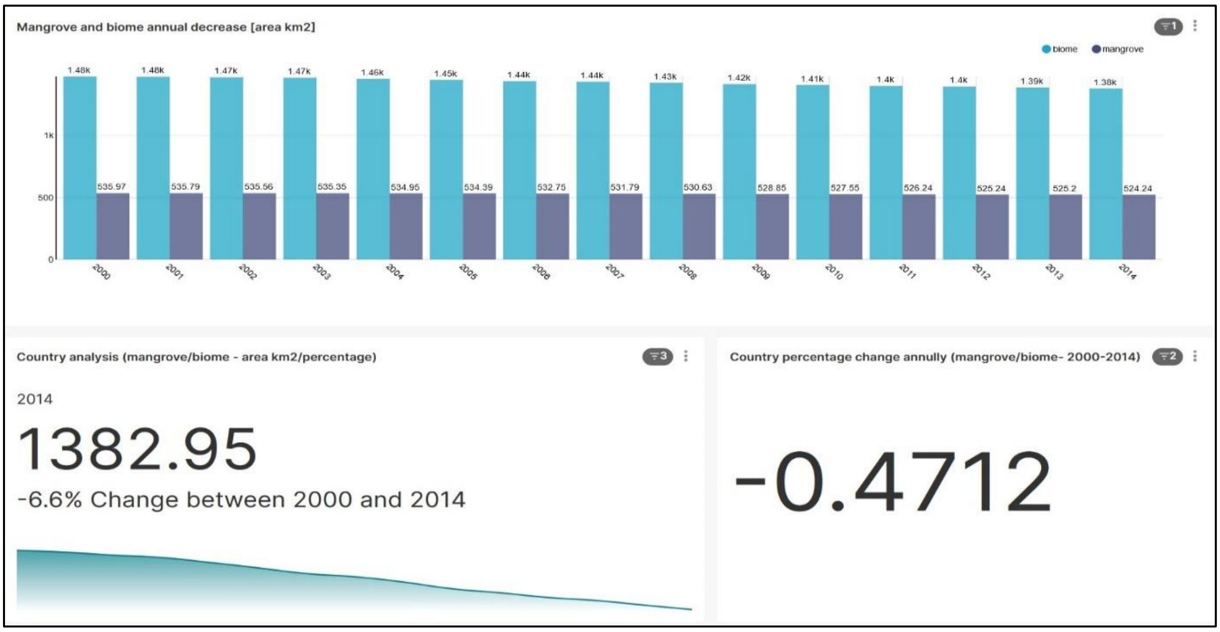

Figure 4-3 Honduras mangrove and biome extent between 2000 - 2014

In many Western African countries, mangrove forest coincides with fossil fuels exploitation and its related infrastructure, which induce mangrove deforestation. Madagascar is one of the African countries that has experienced the highest mangrove and biome extent changes due to anthropogenic activities such as rice cultivation, logging, and shrimp farming. They have experienced around -4.3 % change between 2000 and 2014.

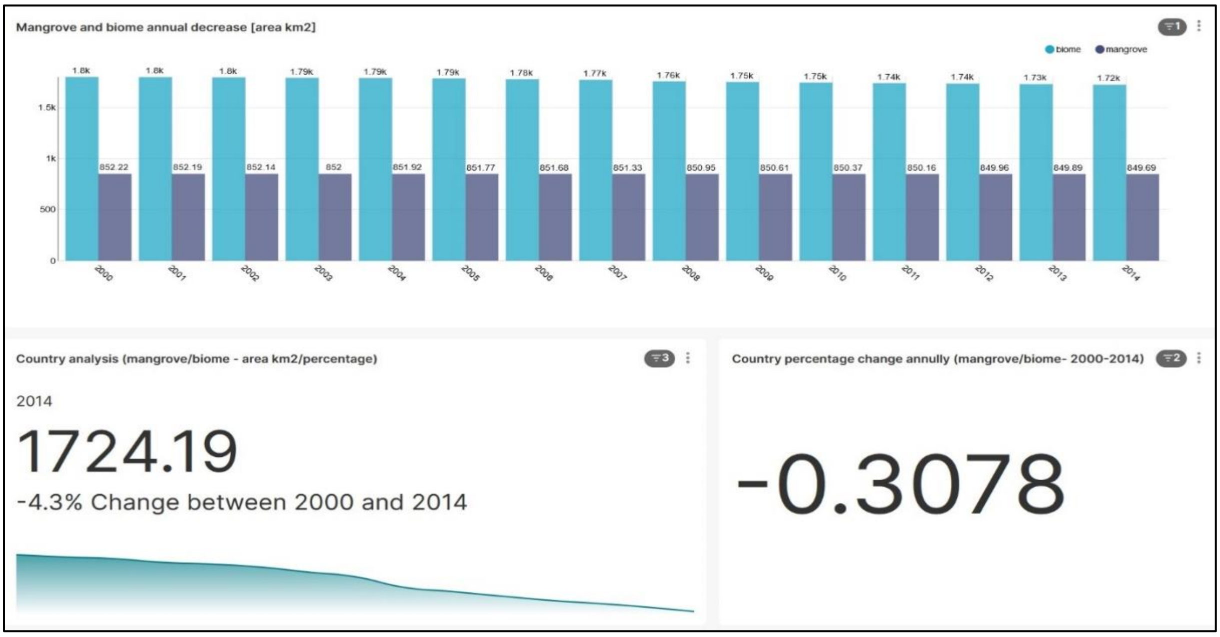

Figure 4-4 Madagascar mangrove and biome extent between 2000 - 2014

In North America, the major threats to mangrove life are low turbidity and elevated levels of nutrient supply, whereas in Mexico coastal development and coastal squeeze are considered as major drivers of mangrove loss(CEC, 2016).

Three natural predominant and widespread threats for seagrasses are:

1. High turbidity levels in water.
2. Phytoplankton proliferation in the water.
3. Sea water temperature increase.

The combination of turbidity and phytoplankton have negative impacts on the amount of light reaching the seafloor, which poses a threat to blue carbon ecosystems, while temperature increase affects seagrasses in terms of growing and development.

Threats for seagrass resulting from human activities are: dredge and fill, aquaculture, shore-line hardening, and nutrient loading. Moreover, nitrogen over enrichment in coastal areas where seagrass grow, results in proliferation of phytoplankton blooms, which makes water clarity decrease and prevents light from reaching seagrass beds (CEC, 2016)

Chapter 5 Conclusion and Recommandation

This chapter brings the current study to an end and conclude all the prominent issues briefly. Additionally, the relevant recommendations were reported based on the outcomes of the study.

5.1 Conclusion

This section will conclude the study by summarizing the key research findings in relation to the research questions: how local system contribute to sequestration and carbon storage and, how carbon sequestration rates and stocks are affected by climate change?

Blue carbon is the carbon that is captured by world's oceans, and it represents more than 55% of green carbon. These three ecosystem mangroves, seagrass, and salt marches are essential and effective in terms of global carbon sinking. In contrast to the rainforests that are able to store the carbon for decades or centuries, blue carbon ecosystem store carbon for millennia.

By using geospatial data into MapX and Superset and creating geospatial layers and dash-boards for blue carbon ecosystems, the global status of mangroves, salt marshes, and seagrasses is indicated.

Mangroves as part of blue carbon ecosystems cover only 0.1 % of Earth continental surface but have been identified as some of the forests with the most richness in terms of carbon on the earth. The depth, type, sequestration rate and stock rate of mangroves vary and depend on the region considered. The average carbon sequestration rate for mangrove is 171 ± 17.1 g Corg /m2 year and mangrove forests average carbon stock rates is 761 ± 45.5 Mg Corg/ha. The values range from 37 to 2477 Mg Corg /ha with a median of 723.4 Mg Corg /ha. However anthropogenic activities impact mangroves forest globally. Between year 2000 and 2014, mangrove and biome have lost 2.3 % and 5.1 % of their area, respectively. Five countries, namely Indonesia, Malaysia, Brazil, Papua New Guinea, and Australia that hold more than 55% of the global mangrove surface, experienced the highest percentage of changes in mangrove and biome extent. For instance, agriculture and conversion of land to aquaculture is by far the major human drivers of mangrove loss in Asia. The other human disturbances such as shrimp-and fishing-industries, water pollution, land exploitation, construction of dams, salt ponds, coastal development, and oil industry are the main contributors to the mangrove loss.

Seagrasses also play a crucial rule in carbon sinking. Asia has the highest carbon sequestration rate. For instance, the sequestration rate for India and Philippines is 77.82- and 22.53-tons CO2/h/year, respectively. Moreover, the sequestration rate for Australia ranges from -2.68- to 22.77-tons CO2/h/year. However, the seagrass decline rate has increased from 0.9 % per year prior to 1940 to 7% per year since 1980. Direct and indirect impacts cause much of the permanent and chronic damages to seagrass meadows. Direct impacts are removal of seagrass during dredging and indirect impacts are overfishing, long-term nutrient pollution and climate change. Turbidity and phytoplankton have impacts on the amount of light reaching seafloor, are threads on seagrass grow and distribution. Raising temperature could also impact seagrass growth and species distribution.

There is not enough reliable data related to the salt marshes. Only few studies were conducted in relation to the salt marshes; they indicate that the carbon sequestration rate for salt marsh is between 0.66 to 68.57 metric tons per hectare per year.

5.2 Recommendations

The following recommends are stated to improve this thesis work, and for further work in the future to get reasonable information:

- Comprehensive studies need to be conducted to fulfill data gaps (geospatial and statistical data) related to blue carbon ecosystems specially for seagrasses and salt marshes.
- There is a need to produce accurate maps and charts so that objects and processes can be seamlessly tracked across the land-water interface as well as over time.
- For illustrating blue carbon in an online open-source platform such as MapX and Superset, there is a need to publish more quantitative data, to categorize them in the same MapX workspace and to create more dashboards to better understand all the environmental issues surrounding blue carbon storage.

- It is worthy to support and foster local technical capacity related to the preservation and/or restoration of blue carbon ecosystems (i.e., remote sensing mapping, carbon measuring and monitoring, etc.)
- In terms of scientific assessment, there is a need to better evaluate spatially and statistically carbon emissions and carbon removal from human activities in blue carbon ecosystem.
- Earth observation data (such as satellite imagery and remote sensing data), in-situ data, local community data, and integrating coastal stakeholders' local expertise, are helpful to assess the blue carbon ecosystems extents, rate and causes of ecosystems loss. Local expertise is critical to validate the results obtained through scientific studies.
- There is a need to develop a global knowledge platform on blue carbon, that would compile the most important global and regional initiatives and datasets, as well as a knowledge repository.

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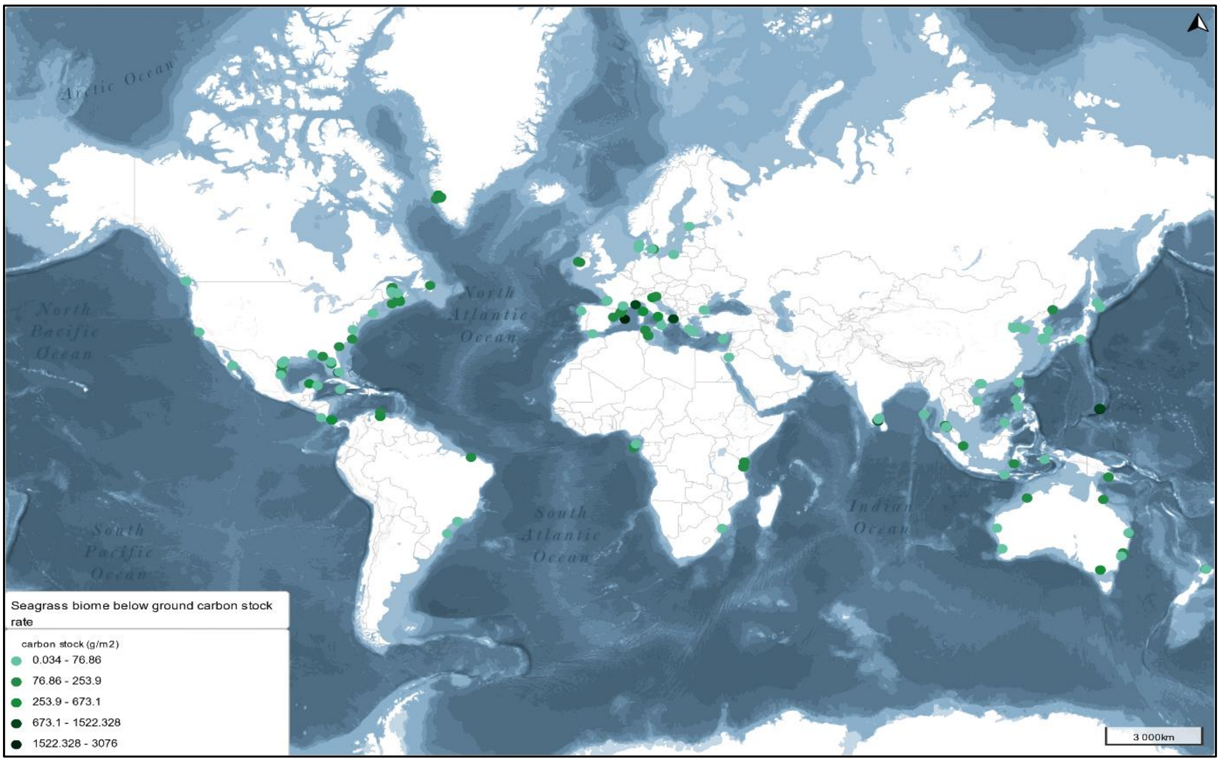
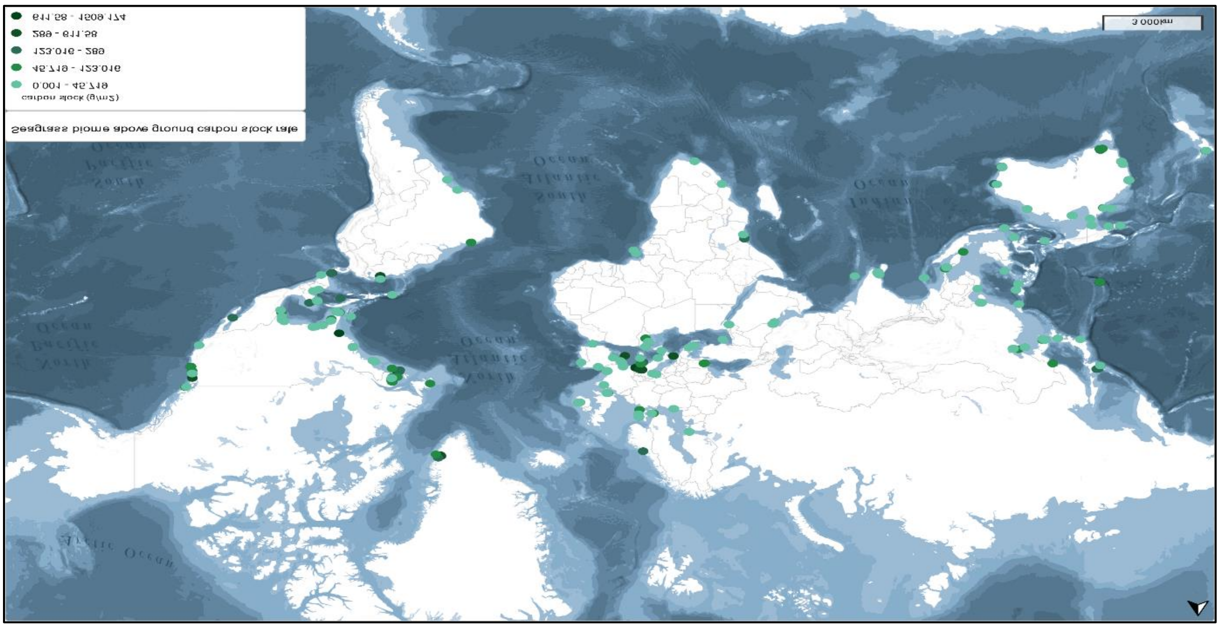
Appendix

Seagrass

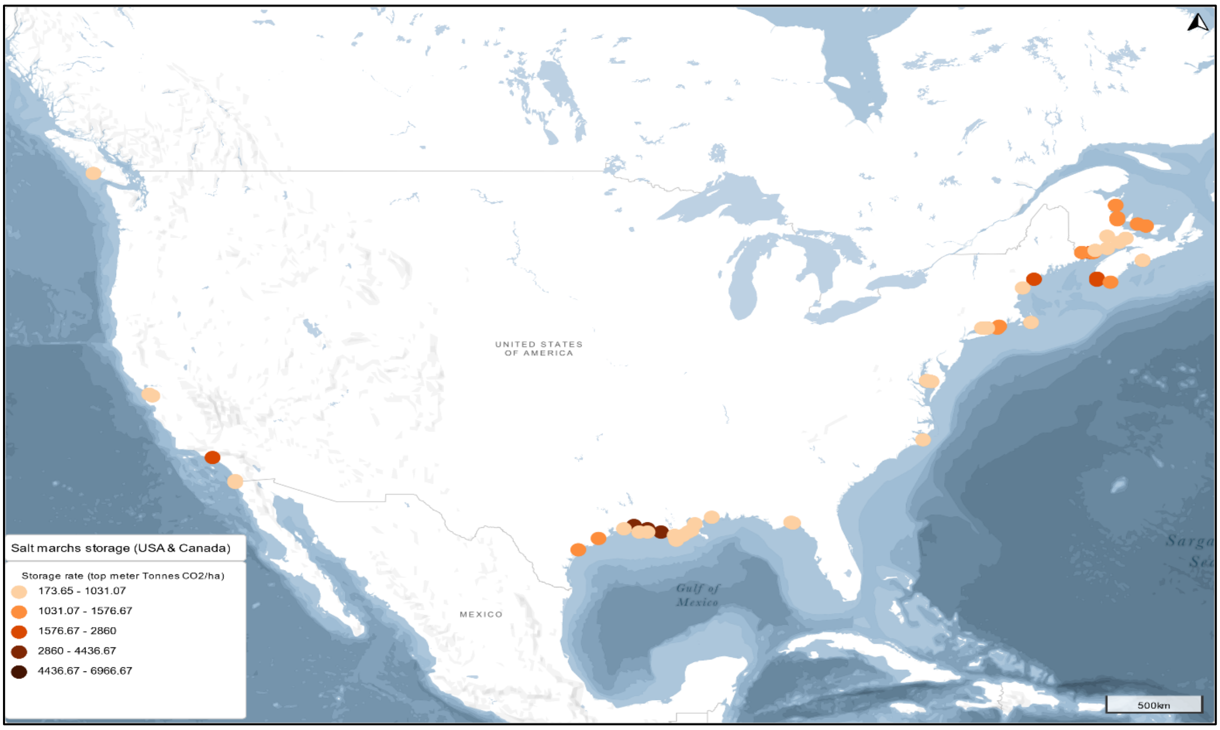


Appendix A 1 Seagrass below ground carbon stock rate

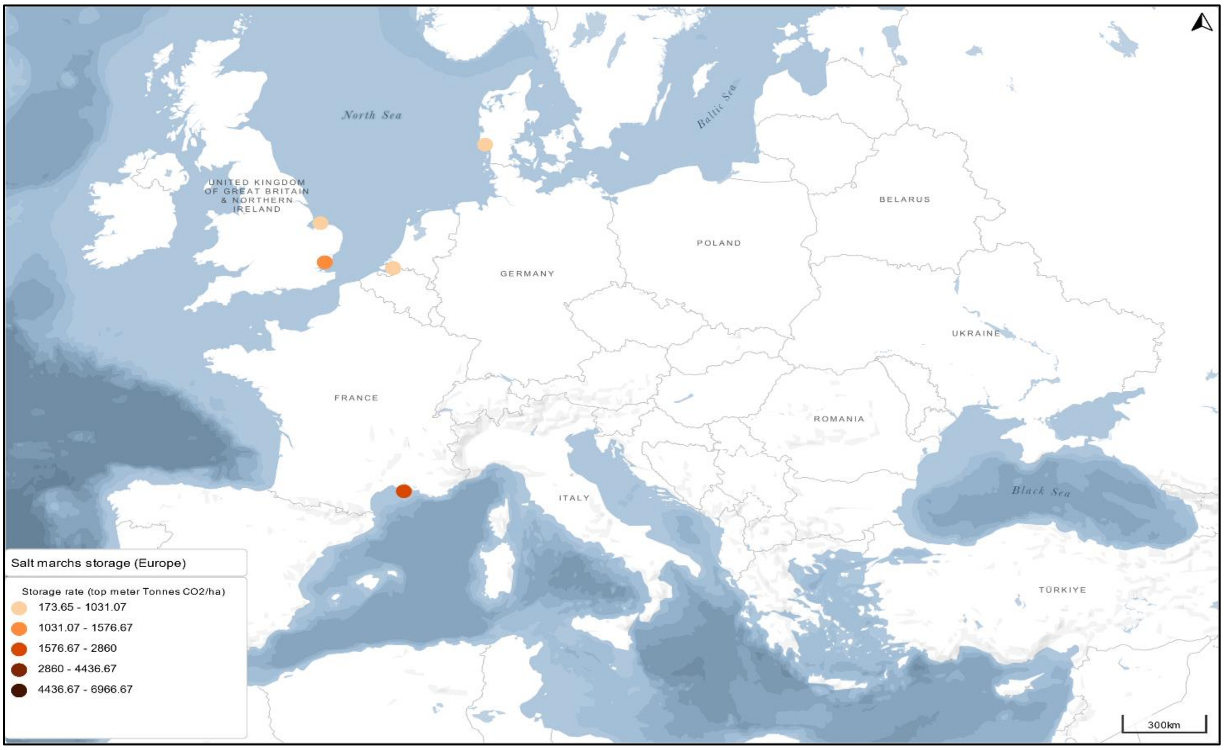


Appendix A 2 seagrass above ground carbons stock rate

Salt Marsh



Appendix A 3 Salt marsh carbon storage rate (USA & Canada)



Appendix A 4 salt marsh carbon storage rate (Europe)