APPLICATION OF InVEST MODEL TO EVALUATE BLUE CARBON DYNAMICS IN THE CHILAW LAGON, SRI LANKA

O.W. Kotagama[1*], K.A.R.S. Perera[1], D.D.G.L. Dahanayaka[2], S. Somaratne[1], S. Pathirage[3]
[1]Department of Botany, The Open University of Sri Lanka
[2]Department of Zoology, The Open University of Sri Lanka
[3]International Union for Conservation of Nature, Colombo Office

INTRODUCTION

Mangrove forests provide a myriad of benefits and ecosystem services to communities (Malik, Fensholt & Mertz, 2015; Getzner & Islam, 2020). The range of ecosystem services provided by mangrove forests account for provisioning services such as providing fuelwood, charcoal, medicine, timber, and generating productive feeding/nursery grounds for commercially vital fish and crustaceans; supporting services such as providing niches for a wide array of biodiversity and facilitating nutrient and biogeochemical cycling; cultural services such as providing sites for enjoyment, relaxation and study; and regulating services such as trapping and removal of pollutants, providing protection against natural disasters such as tsunamis, storm surges, and coastal erosion, facilitating floodwater retention and, most in line with the present study, the sequestration, and storage of carbon (Chang-yi et al. 1997; Wang et al. 2003; Giesen et al. 2007; Miththapala, 2008; Ong and Gong 2013; Nehren et al., 2017).

Mangrove forests are considered superior carbon sinks with high carbon capture and storage capacity (Donato et al., 2011; Perera & Amarasinghe, 2015). Together with seagrass beds and salt marshes, mangroves make up ecosystems commonly referred to as Blue Carbon Ecosystems. These ecosystems play major roles in the carbon dynamics of aquatic environments owing to the prevailing geochemical characteristics that promote the storage of carbon over long periods. Sedimentation owing to tidal action and anaerobic waterlogged conditions present deter decomposition of organic matter allowing for long term storage of carbon. The major carbon reserves associated with these ecosystems are found in the soil (Twilley et al., 2018) thus subject to considerably low levels of natural disturbance as well.

However, global warming and its effects are predicted to have a considerable detrimental effect on coastal ecosystems throughout the world (IPCC, 2021). Sea level rise (SLR) is a threat arising from global warming, which has gained considerable attention recently (SROCC, 2021). The rates of SLR have been recorded to be faster in the 20th century than in any prior century over the last three millennia (Fox-Kemper et al., 2021).

Rising sea levels bring about effects that are undesirable to coastal ecosystems as well as communities associated with them. Local studies carried out concerning SLR have identified the loss of residential areas, commercial fishing areas, and mangrove ecosystems as direct impacts of SLR (Perera et al., 2018; Gopalakrishnan et al., 2020). Owing to the heightened capacity of mangrove forests to sequester and store carbon, they represent an ideal tool that can be used in the mitigation of climate change despite the threats they face. However, the establishment of conservation policies and management plans in the face of SLR requires a thorough understanding of the impacts of these processors on mangrove forests.

The present study aims to provide an understanding of the changes that occur to blue carbon stocks of mangroves in the face of rising sea levels. The study makes use of the Integrated Valuation of Ecosystem Trade-offs (InVEST) (Sharp et al., 2014), Coastal Blue Carbon (CBC) tool created for the Natural Capital Project by Stanford University, to give predictions regarding the changes that may occur to blue carbon dynamics with SLR. The model makes use of a bookkeeping method (Houghton, 1999) in which a time series of areas subject to different land use land cover (LULC) types are coupled with response curves of carbon pools in ecosystems after a unit change of land use. In the present study, SLR scenarios were considered about the best and worst possible pathways of global trajectory proposed in IPCC, 2021. The InVEST model considers changes to the carbon pools concerning the present (2021) LULC classification and identifies changes based on the alternative scenarios proposed.

METHODOLOGY

The site selected for the study was the Chilaw Lagoon complex. The lagoon is found in Pambala 7°31'08.5"N 79°49'26.6"E on the Western coast of the island in the Puttalam District of the North-western province. The average maximum and minimum temperatures recorded were 31^{0}C and 24 ^{0}C respectively. The average rainfall is between 195 mm – 30 mm. The lagoon is 29.5 km in length and 02 km wide at its broadest and has a surface area of approximately 1800 ha.

The InVEST, Coastal Blue Carbon tool is an open-source tool that relies on the input of different carbon pool data (biomass carbon, soil carbon, and litter carbon) as well as raster maps that show the changes to land use patterns of the relevant area. The tool has two components; the CBC pre-processor and the main CBC model. Two scenarios relating to the SSPs[1] introduced in IPCC AR6 were taken into consideration and models were generated for the years 2021, 2100, and 2150 to represent the patterns in carbon dynamics.

The CBC pre-processor and main model both require raster maps for each of the considered scenarios as well as the present land use pattern which will be used as a baseline scenario for the predictive modelling. For this process, digital terrain data of the Chilaw lagoon was obtained from the National Survey Department and used to create Digital Elevation Models (DEMs) which were reclassified based on inundation scenarios, considering the upper level of inundation (table below).

Sea level rise scenario[2]	Predicted sea-level rise	
	2100	2150
Very low GHG emissions scenario (SSP 1-1.9)	0.55 m	0.86 m
Very high GHG emissions scenario (SSP 5-8.5)	1.01 m	1.88 m

DEMs were overlaid on an updated land use map and the extent of inundation relating to SLR scenarios was obtained. The update maps were then converted into rasters which were utilized for the InVEST model. The developed raster maps were introduced into the CBC pre-processor and the biophysical table and CBC transition tables were obtained.

The biophysical table and CBC transition tables were generated by the pre-processor were completed with the use of both primary and secondary data. Biomass carbon was calculated through field studies while soil carbon data was obtained from published sources (Cooray et al., 2021). The appropriately completed tables were introduced into the CBC main model.

[1] Scenarios based on Shared Socioeconomic Pathways (SSP) that reflect scenarios of projected socioeconomic global change and are used to derive greenhouse gas emissions scenarios with different climate policies – the baseline pathways used in IPCC 2021.

[2] Scenarios based on Shared Socioeconomic Pathways (SSP) that reflect scenarios of projected socioeconomic global change and are used to derive greenhouse gas emissions scenarios with different climate policies – the baseline pathways used in IPCC 2021.

The outputs of the main tool are produced in the form of raster maps corresponding to several different carbon dynamics. Each map (Annex 01) is made up of a certain number of pixels representing an area of 0.01 ha. By taking into consideration classified pixel groups, information on carbon accumulation, carbon stocks, carbon emissions, carbon sequestration, and carbon stock valuation were obtained.

It is important to note that mangrove ecosystems retain a major portion of blue carbon reserves within their soil accounting for about 70% - 80% of total carbon, whereas the mangrove trees would account for the remaining 40% - 30% (Cooray et al., 2021, Donato et al., 2014). Thus, the level of disturbance to blue carbon reserves owing to inundation and the subsequent death of mangrove forests is considered to be 30% (0.3)[3] of the total carbon present within the ecosystem (i.e. living above ground and below ground carbon from trees and soil carbon).

RESULTS AND DISCUSSION

Changes to the carbon dynamics and valuation of carbon in mangrove forests of the Chilaw lagoon were modelled relating to rising sea levels with the use of the InVEST CBC model. Two scenarios relating to the SSP introduced in IPCC AR6 were taken into consideration and models were generated for the years 2021, 2100, and 2150. The scenarios taken into consideration indicate two contrasting global trajectories regarding global warming. Scenario 1 (SSP 1 – 1.9) is regarded as the best possible pathway, representing a global corporation, achievement of net-zero, and a gradual but persuasive shift toward a greener world. Thus, the impacts of climate change would be managed and SLR would be minimal. Scenario 4 (SSP 5 – 8.5), however, represents a scenario in which high challenges to mitigation exist. Absence of global corporation, prioritization of regional development, regional rivalry, and the absence of net-zero and associated mitigation results in the worst possible outcome of global warming and surpassing the 2 ^{0}C upper limits to warming (IPCC, 2021). Thus, in such a background, SLR would be highest. Accordingly, the highest extent of inundation in mangrove forests and the largest disturbance to blue carbon dynamics were found in this scenario.

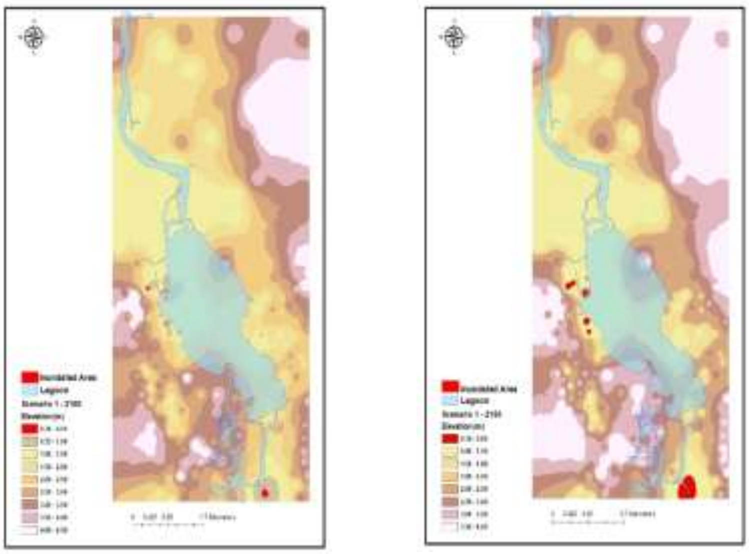

Figure 1: DEMs developed for scenario 1 (left: 2100 right:2150)

[3] Level of disturbance is to be included in the InVEST CBC model based on appropriate assumptions and deductions.

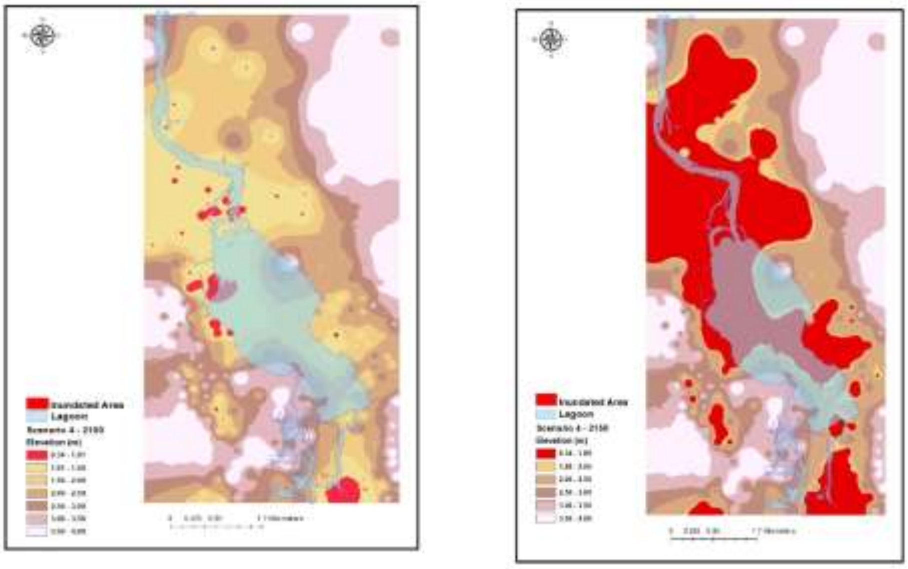

Figure 2: DEMs developed for scenario 4 (left: 2100 right:2150)

In relation to blue carbon dynamics, total ecosystem carbon in the Chilaw lagoon was modelled as 990.21 MgC in 2021. 446,700 MgC of total ecosystem carbon was found to accumulate in the Chilaw lagoon between the years 2021 – 2100 under all scenarios. Between 2100 and 2150, when the impacts of SLR become evident, carbon accumulation is seen to decline between the two scenarios. 282,083.85 MgC of carbon was found to accumulate in scenario 1 while only 273,219.6 MgC of carbon was found to accumulate in scenario 4. Total carbon stocks indicate values of 991.52 MgC and 2049.93 MgC for the years 2021 and 2100 respectively. In 2150, when the impacts of SLR are more pronounced, carbon stocks are found to decline and indicate values of 2717.13 MgC for scenario 1 and 2677.49 MgC for scenario 4, respectively. Following a similar trend, carbon sequestration was also found to decline in scenario 4 when compared to scenario 1. In scenario 1 the total carbon sequestration between 2021 – 2150 was 728,200 MgC while under scenario 4 the expected carbon sequestration is 711,400 MgC. Carbon emissions were found to sharply increase. 528.10 MgC and 8391.57 MgC was found to be emitted under scenario 1 and scenario 4 respectively. The higher level of emission in scenario 4 is associated with the level of disturbance arising from SLR. Finally, the monetary value of carbon sequestration (in LKR billion) as per the present price of carbon credit in the European Carbon Market for each scenario by the year 2150 indicates LKR (bn) 39,205 in scenario 1 and LKR (bn) 38,305 in scenario 4. The raster maps generated from which these results were obtained are included in Annex 01.

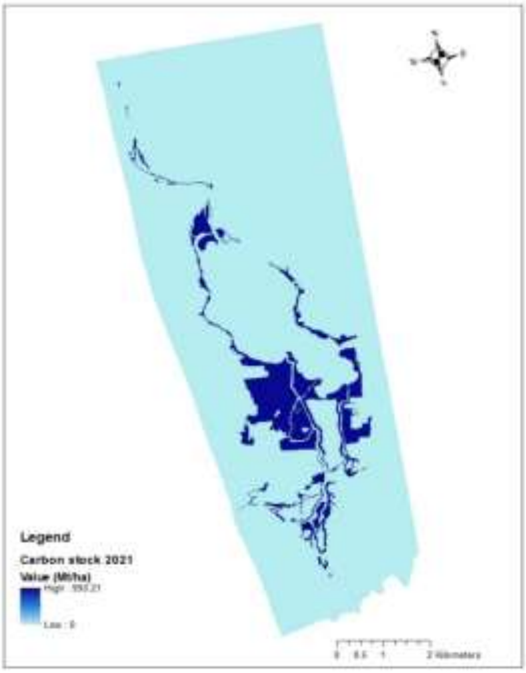

Figure 3: Blue carbon stock in Chilaw Lagoon (2021)

In the present study, we assume that the inundation of mangrove forests results in the loss of mangrove cover and thus the loss of their sequestration capacity. Numerous studies have concluded that the responses of mangroves to SLR would result in vertical or horizontal migration (landward or seaward). However, given the proximity of human settlements, shrimp farms, and other land-use types close to the mangrove forests and reduced sedimentation rates, such migration is expected to be unlikely.

CONCLUSIONS/RECOMMENDATIONS

The InVEST model which was applied in the present model represents an ideal tool to better understand the extent of impacts on different SLR scenarios. Extending studies to the other mangrove forests and associated blue carbon reserves on the island can help to obtain a more holistic and complete understanding of the dynamics of blue carbon about rising sea levels. The InVEST model can be also used to develop an understanding of changes to ecosystems in light of alternative management plans, hence allowing the determination of the most suited plan to be implemented.

The information generated about SLR and carbon dynamics of the Chilaw lagoon help draw focus to the large carbon reserves and carbon sequestration capacity present. Considering the limited extent of mangrove forests in the Chilaw lagoon this is a remarkable finding, consolidating the superior carbon storage capacity of mangroves. Further studies on the impacts of different local climatic and physiochemical characters of the lagoon com. Influence on factors such as temperature, precipitation, salinity, tidal patterns, period of inundation, nutrient availability, and many other localized factors are found to influence the process of carbon sequestration and other carbon dynamics (Singh et al., 2022; Kauffman et al., 2020; Perera & Amarasinghe, 2018). Thus, a broader consideration of the changes in such factors in the face of rising sea levels can be used to generate a much broader understanding of carbon dynamics.

The valuation of carbon through the InVEST model alone shows the extensive potential for the incorporation of bio-fin mechanisms such as Payment for Ecosystem Services (PES). Such mechanisms when appropriately employed can be used as means to generate revenue which can be used for community upliftment as well as conservation. Thus, successful community conservation models can be developed which can help the conservation of mangroves as well as the rehabilitation of degraded areas.

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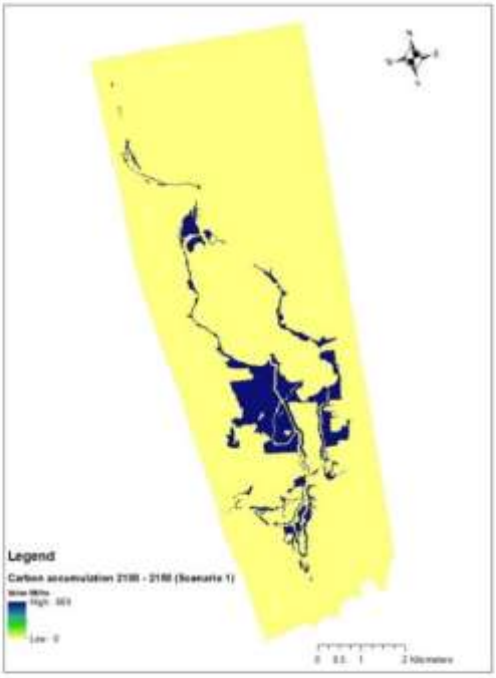
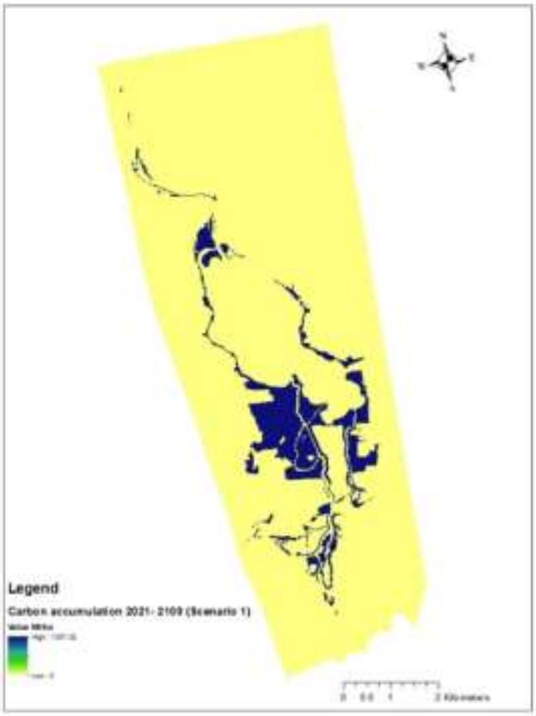
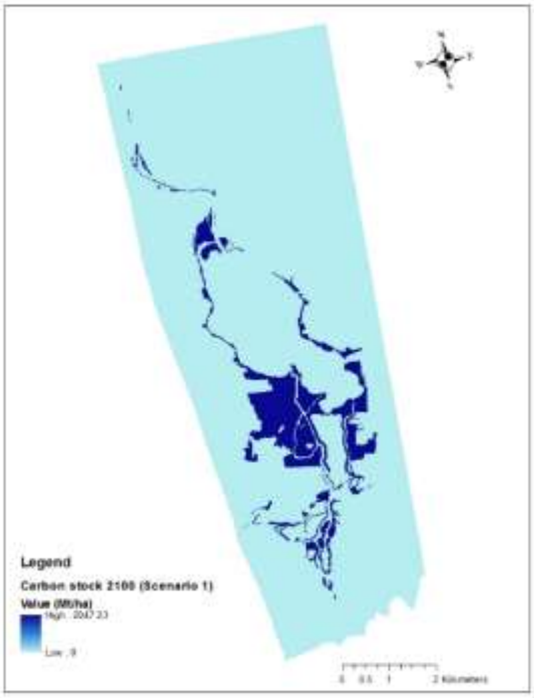
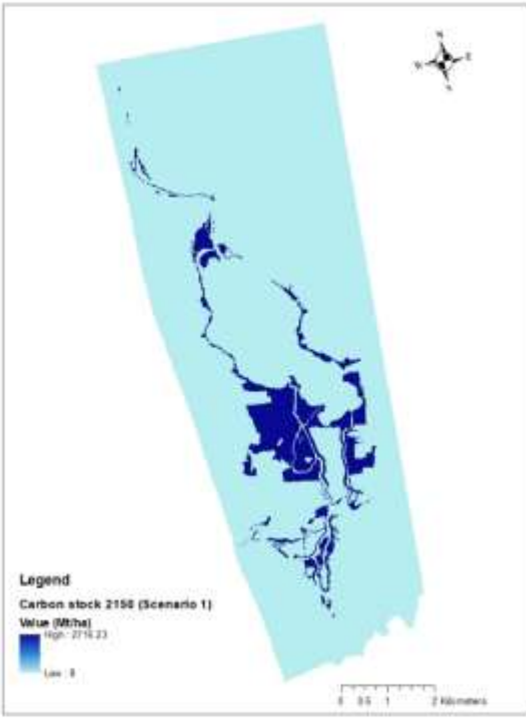
ANNEX 01: RASTER MAPS PRODUCED FROM THE MODEL.

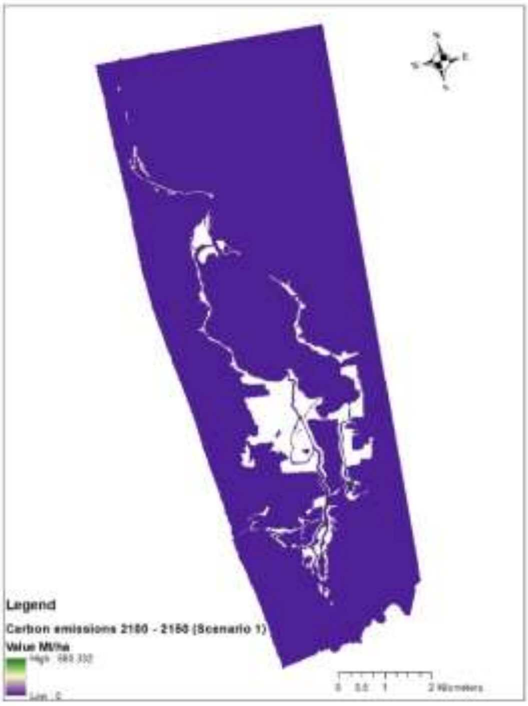
Scenario 1

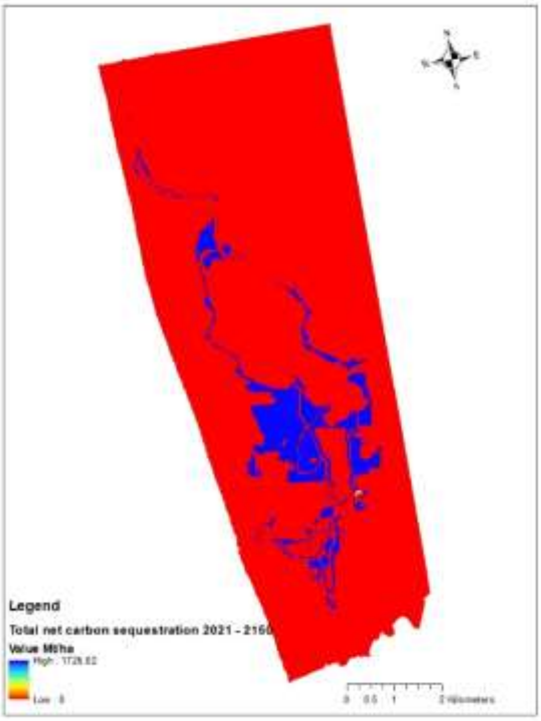


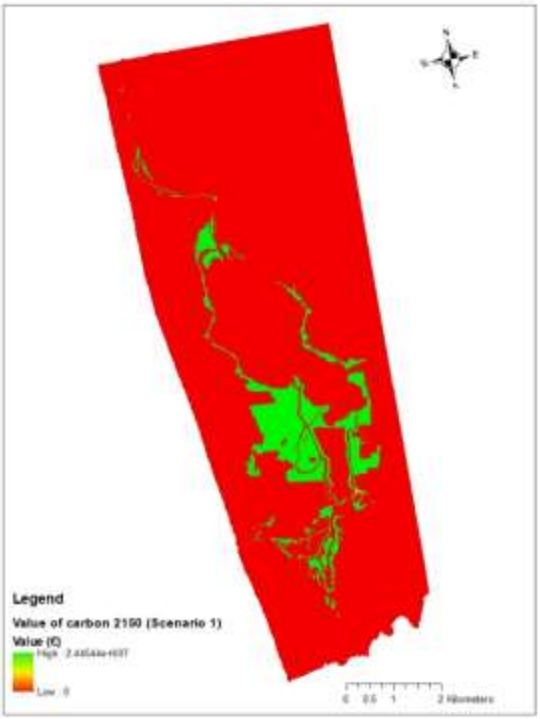


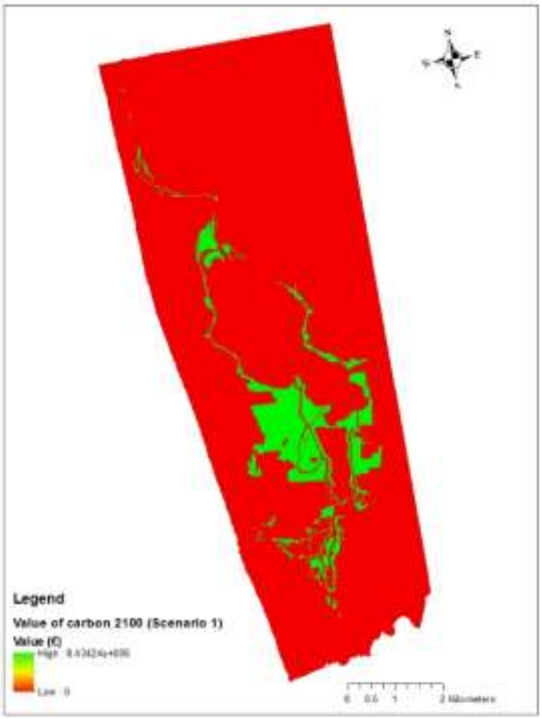




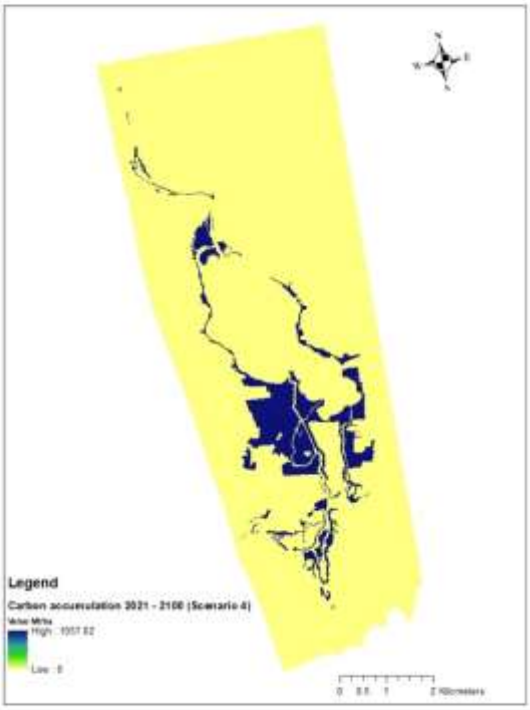

Legend
Carbon emissions 2100 - 2150 (Scenario 1)
Value Mt/ha

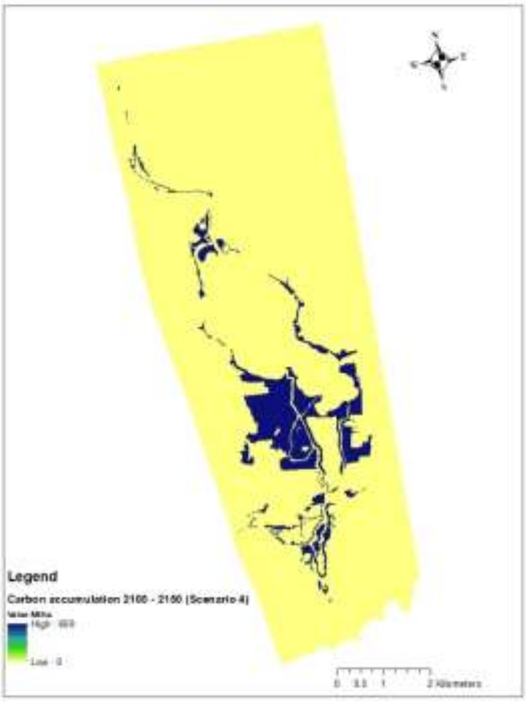

Legend
Total net carbon sequestration 2021 - 2150
Value Mt/ha
High : 1728.82
Low : 0

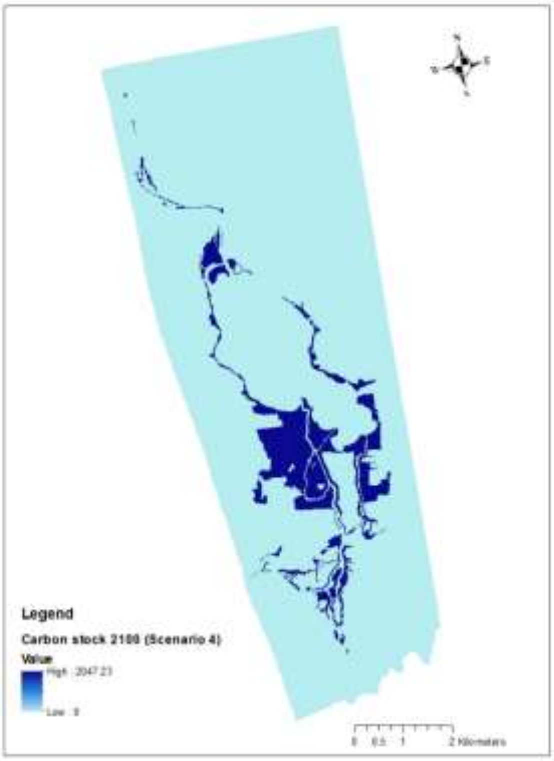

Legend
Value of carbon 2150 (Scenario 1)
Value (€)
Low : 0

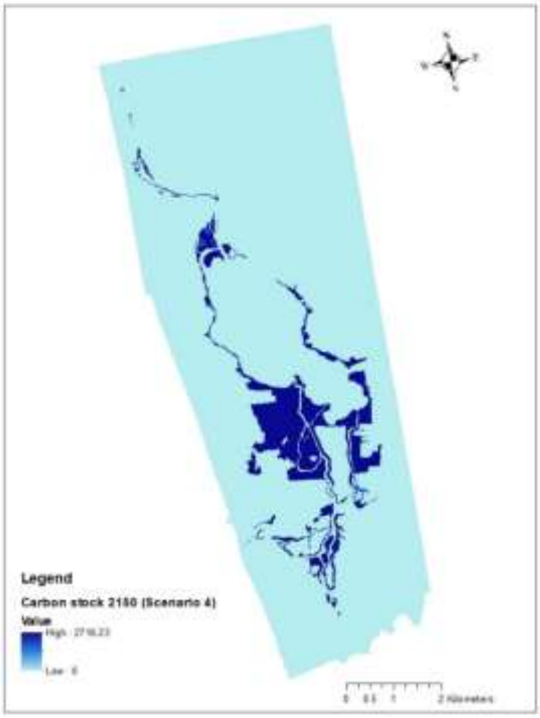

Legend
Value of carbon 2100 (Scenario 1)
Value (€)
Low : 0

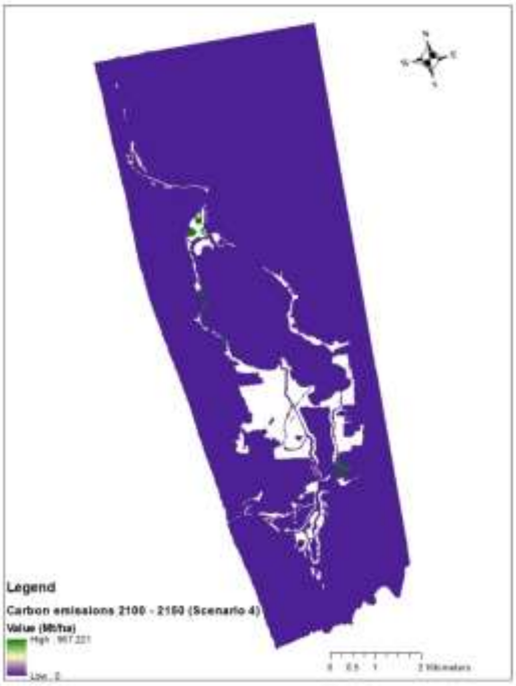
Scenario 4

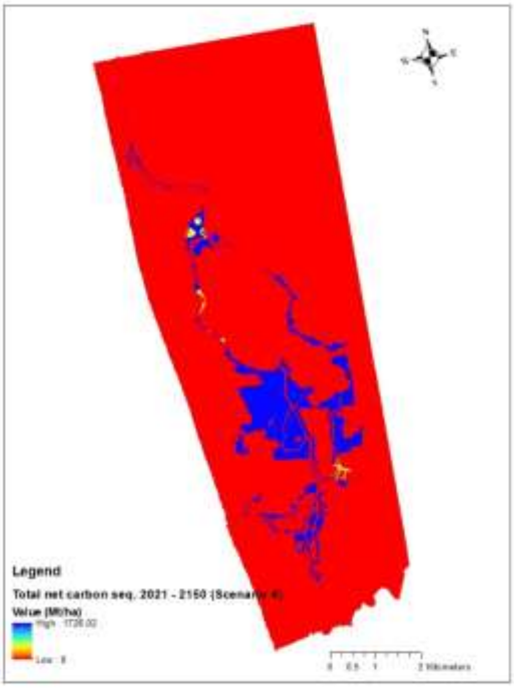

Legend
Carbon accumulation 2021 - 2100 (Scenario 4)
Low : 0
0 0.5 1 2 Kilometers

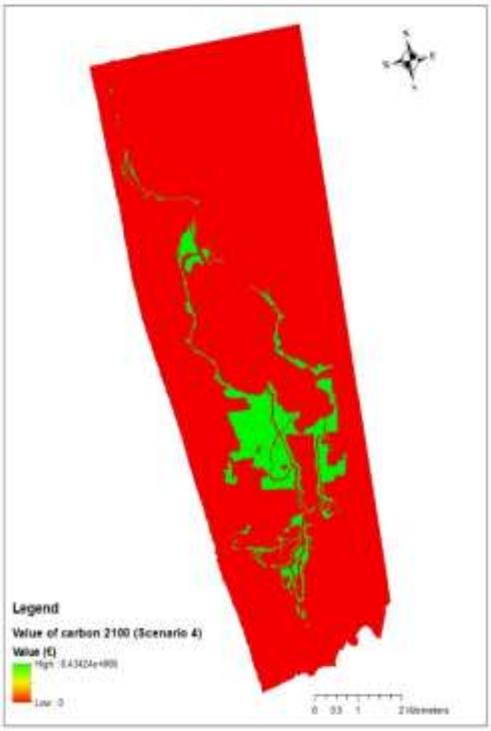

Legend
Carbon accumulation 2100 - 2150 (Scenario 4)
Low : 0
0 0.5 1 2 Kilometers


Legend
Carbon stock 2100 (Scenario 4)
Value
High : 2047.23
Low : 0
0 0.5 1 2 Kilometers


Legend
Carbon stock 2150 (Scenario 4)
Value
Low : 0
0 0.5 1 2 Kilometers


Legend
Carbon emissions 2100 - 2150 (Scenario 4)
Value (Mt/ha)


Legend
Total net carbon seq. 2021 - 2150 (Scena
Value (Mt/ha)


Legend
Value of carbon 2100 (Scenario 4)
Value (€)


Legend
Value of carbon 2150 (Scenario 4)
Value (€)