

Article

Potential Distribution and Carbon Sequestration of *Rhizophora mangle* L. in El Vizcaíno Biosphere Reserve, Baja California Sur, Mexico

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Abstract: Mangroves are a type of vegetation distributed in warm areas of the planet. Despite their importance, this flora is seriously threatened by both human activities and climate change. One of the main benefits provided by mangroves is carbon capture and storage, which is key for climate change mitigation. The main objective of this study was to identify the potential distribution and carbon sequestration potential of *Rhizophora mangle* L. in El Vizcaíno Biosphere Reserve. Potential distribution models were obtained for Baja California Sur, Mexico, using the MaxLike algorithm. For each projection, we used bioclimatic variables from the WorldClim project for current and future conditions (2050 and 2070), two Shared Socioeconomic Pathways (SSP2-4.5 and SSP5-8.5) and three General Circulation Models (ACCESS-CM2, EC-Earth3-Veg and MPI-ESM1-2-HR). The potential distribution models were developed within the perimeter of El Vizcaíno Biosphere Reserve as a case study to establish the potential for carbon sequestration under different climate change scenarios. Our results show a possible future carbon sequestration from 10,177,174 Mg of CO₂ and up to 14,022,367 Mg of CO₂ for the ACCESS-CM2 SSP5-8.5 to 2070 and MPI-ESM1-2-HR SSP2-4.5 to 2070 projections, respectively. Mangrove species such as *Rhizophora mangle* can be an important part of climate change mitigation and adaptation.

Keywords: ecological niche; mitigation; carbon sinks; red mangrove



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1. Introduction

Mangroves are a plant community that inhabits the banks of rivers or lagoons, are strongly influenced by seawater and withstand strong changes in tide levels and salinity [1,2]. Depending on climate, soil conditions, topography and water salinity, this type of vegetation can grow as trees or shrubs [3]. Mangroves are very important because they provide habitat for many terrestrial and marine species, and the functioning of the ecosystem provides extensive benefits to human communities, which are called ecosystem services [4]. Mangroves can provide human populations with food, building and raw materials, water and recreational and tourist areas, among others [3,5].

In addition, mangroves provide various services that help ensure the well-being of coastal communities. They create a wall between land and sea, protecting the coasts from storms and erosion [5,6], and can even attenuate tsunami-induced waves [7]. In addition, mangroves are among the world's most carbon-rich forests and can help to reduce the impact of increasing CO₂ concentrations in the atmosphere [8]. Unlike tropical forests, the storage of organic carbon in these coastal ecosystems occurs primarily in the soil itself, and less so in the plant material found above ground [5]. The sequestration of carbon

dioxide by mangroves is almost 30% higher than that of the rainforests, thus increasing their climate change mitigation potential. For this reason, mangroves are an important component of socioecological systems, providing an excellent example of synergy between mitigation, adaptation and sustainable development. A very good strategy to encourage cooperation between public and private actors and the users of environmental services is blue carbon, which is encouraging the creation of alliances between public, private and social entities through mechanisms of payment for environmental services, credits or the voluntary carbon market [9].

Mexico has the fourth largest mangrove area in the world with 905,086 hectares [10] and is one of the countries with the largest extensions of blue carbon capture and storage ecosystems [11,12]. In Mexico, the most important actions in favor of mangroves have been the inclusion of four species (*Rhizophora mangle* L., *Laguncularia racemosa* (L.) C.F. Gaertn., *Avicennia germinans* (L.) L. and *Conocarpus erectus* L.) in an Official Mexican Norm (NOM), NOM-059-SEMARNAT-2010, which considers these species in the threatened category. In addition, the protection of the mangrove ecosystem is broadly considered and any change that affects its integrity is prohibited, which has been one of the best strategies of the Mexican Government to halt the destruction and promote the recovery of this ecosystem [10]. Another important tool to conserve ecosystems and protect mangroves are Natural Protected Areas (PNAs), which aim to preserve natural environments and their ecosystems in order to ensure the balance and continuity of evolutionary and biological processes. Additionally, PNAs also contribute to enabling the adaptation of biodiversity and to addressing the effects of climate change. By functioning as natural deposits of significant amounts of carbon in the biomass of the ecosystems present in them, PNAs serve as natural carbon sinks, thus contributing to the mitigation of climate change.

The El Vizcaino Biosphere Reserve (REBIVI), with an area of 2,546,790 hectares [13], is the most extensive PNA in Mexico, and one of the largest protected areas of the American Continent. Examples of the valuable assets of the area are its natural attractions, with almost 3500 hectares of mangroves [10].

However, despite the importance of mangroves, the ecosystem is highly threatened. The global loss of mangroves has been attributed mainly to human activity such as deforestation, conversion to aquaculture and urban development [14]. One of the consequences of these processes is the release of large amounts of previously stored carbon into the atmosphere, contributing substantially to global warming [15,16]. The main goal of this study is to estimate the potential carbon sequestration of *R. mangle* in El Vizcaino Biosphere Reserve under different climate change scenarios.

2. Materials and Methods

2.1. Study Area

The El Vizcaino Biosphere Reserve (REBIVI) is located in the northern part of Baja California Sur (Figure 1). The main economic activities in the reserve are fishing, aquaculture, alternative tourism and agriculture. The landscapes of the REBIVI present a unique scenic beauty, with many endemic species such as the pronghorn peninsular (*Antilocapra americana peninsularis*) and migratory species such as the gray whale (*Eschrichtius robustus*) [17], as well as the cultural attraction of the cave paintings in Sierra de San Francisco, which have become a World Heritage Site [18].

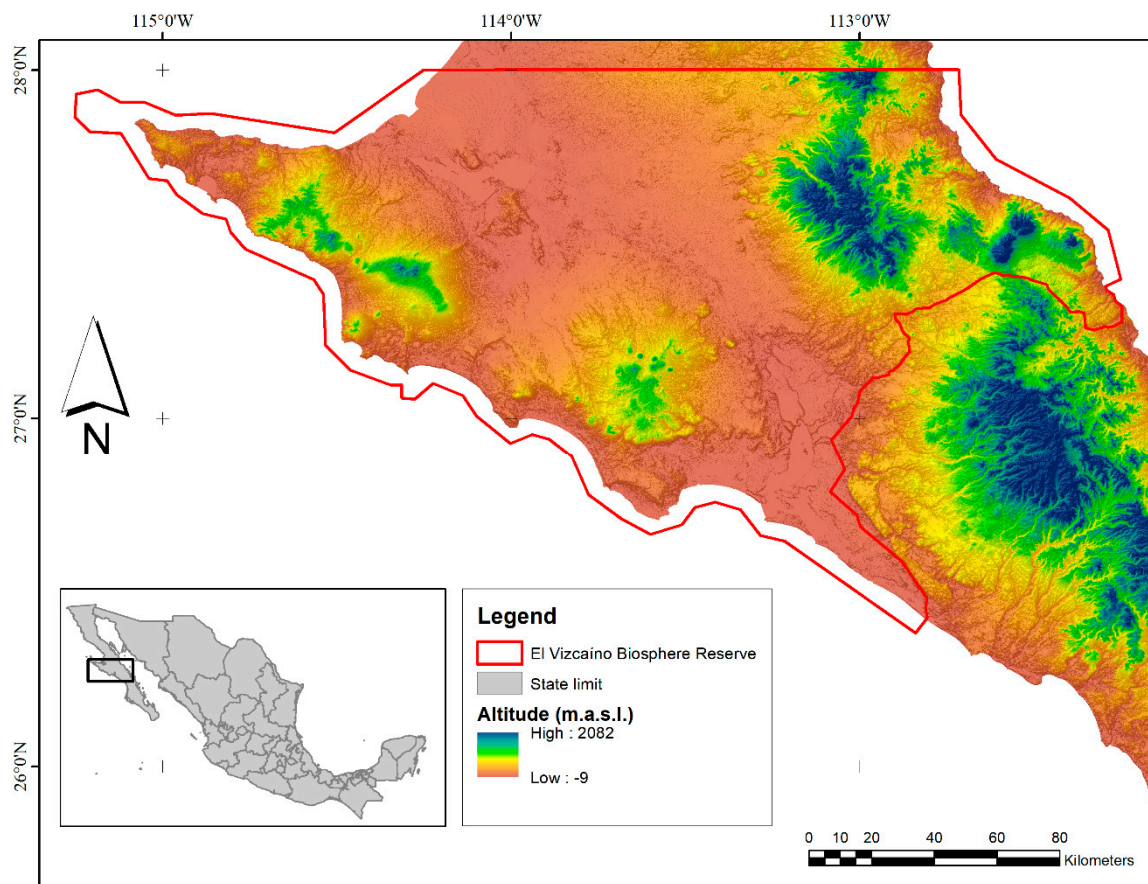


Figure 1. Location of El Vizcaino Biosphere Reserve.

2.2. Potential Distribution Maps

To study the likely patterns of the impact of climate change on the distribution of species, the use of Ecological Niche Modeling (ENM) has been recurrently used to envision what shape the hypothesized environmental changes suggested by suitable scenarios could take in the future. ENM is a tool that uses records of the occurrence of the species and bioclimatic variables to identify and analyze the relationships between these variables and the ecological behavior of the species, which eventually has a geographic realization [19,20].

To generate the potential distribution models of *R. mangle*, the modeling area was defined from the coastline of all of Mexico to a distance of 40 km inland [21]. Records of presence from the National Biodiversity Information System (SNIB) of the National Commission for the Knowledge and Use of Biodiversity (CONABIO) of Mexico and the Global Biodiversity Information Facility (GBIF) were used for this purpose. Records without coordinates, with repeated coordinates and all of those outside the modeling area were excluded. The study verified that each presence record was in the corresponding locality using a geographic information system and Google Earth Pro © 2022 Google LLC ver. 7.3.6.9796 software. A total of 186 presence records were used. Most of the presence records used fall within the period 1970–2000, and to a lesser extent, within the periods 1960–1970 and 2000–2010. Meteorological information from those years was also used to generate the base bioclimatic variables [22].

The study used bioclimatic variables at “current” conditions [22] (<https://www.worldclim.org/data/worldclim21.html> (accessed on 19 April 2023)), as well as elevation and future bioclimatic variables (https://www.worldclim.org/data/cmip6/cmip6_clim30s.html (accessed on 14 April 2023)) with 30s (~1 km²) resolution from two Shared Socio-economic Pathways (SSPs) (SSP2-4.5 and SSP5-8.5) at 2050 (2041–2060) and 2070 (2061–2080)

from the WorldClim project (WorldClim is a widely used global database of climate data widely used for environmental modeling).

Three General Circulation Models (GCMs) were used: the Australian Community Climate and Earth System Simulator (ACCESS-CM2), the European Research Consortium EC-Earth (EC-Earth3-Veg) and the Max Planck Institute Earth System Model (MPI-ESM1-2-HR). These GCMs were selected because they perform well in projecting changes in temperature and precipitation in North-Central America and South-Central America [23].

To avoid correlated variables, we applied a Pearson correlation analysis (Pearson > 0.8) to the 19 bioclimatic variables dataset at “current” conditions and to the elevation variable, although a widely used rule of thumb is to avoid correlations with Pearson correlation values > 0.7 [24–26]. Having many correlated variables could result in an overfitting of the models [26]. Finally, to generate the potential distribution models, the variables Bio5 (the maximum temperature of the warmest month), Bio6 (the minimum temperature of the coldest month), Bio13 (the precipitation of the wettest month), Bio14 (the precipitation of the driest month) and elevation were selected based on ecological criteria. In addition, temperature extremes, especially minimum temperatures, may be of greater importance for the distribution of species [27]. We performed a Principal Component Analysis (PCA) with all variables at “current” conditions to determine the contribution of the selected layers to the variability in the data. These five variables explain 95% of the variation in the data.

It is important to highlight that Rodríguez-Medina et al. [28] found that, over large areas, the main characteristics of the distribution of mangrove ecosystems are determined by climate and topography. For instance, Cavanaugh et al. [29] and Record et al. [21] noted that low temperatures limit the distribution of mangrove species at higher latitudes. Likewise, according to Osland [30], the main climatic factors controlling the limits of mangrove presence in the western Gulf of Mexico and western North America are precipitation and minimum temperature. In addition, it is important to consider extreme values rather than just averages to understand mangrove range limits [30,31].

To obtain potential distribution models we used the R programming language package MaxLike Library [32], which provides a likelihood-based approach to modeling species distributions using presence only data. In addition, we used the libraries raster ver. 2.3–12 [33], rgdal ver. 0.9–1 [34], sp ver. 1.0–16 [35], and tcltk2 ver. 1.2–10 [36], in R ver. 3.1.2 [37]. Finally, we used the tool Partial ROC of SDM Performance from NicheTool-Box [38] (<http://shiny.conabio.gob.mx:3838/nichetoolb2/> (accessed on 1 November 2023)) to evaluate a potential distribution model at current conditions. The parameters used to evaluate the model were a proportion of omission of 0.05, a random points percentage of 50% and a number of iterations for the bootstrap equal to 1000. Significance was assessed by counting the number of bootstraps with AUC-ratio values < 1 [39]. To define the presence/absence value at current and future conditions, the probability of presence values were obtained by “extracting” the values of the potential distribution map at current conditions with the coordinates of all of the presence records used in the generation of the models (training and validation). According to Pearson et al. [40], the minimum probability of presence value obtained with this procedure is called the Lowest Presence Threshold (LPT), and ecologically interpreted as the identification of predicted pixels that are at least as suitable as those in which the presence of the species has been recorded. This value, the LPT, was used as a reference to define our presence/absence value in the potential distribution maps.

Additionally, to perform the analyses presented in this paper, the potential distribution models obtained were cut with the state boundary of Baja California Sur, and subsequently with the boundary of the REBIVI Protected Natural Area.

Finally, to explain the differences in 2050 and 2070 in *R. mangle* distribution areas, the values of the environmental variables used in the various projections for each scenario (Ssp2 45 and Ssp5 85) and for each GCM were examined. First, each potential distribution map was converted into points (one point per pixel). From these points, the values for tem-

perature (Bio5 and Bio6) and precipitation (Bio13) were extracted from their corresponding environmental datasets.

2.3. Carbon Sequestration Potential

The estimation of the carbon sequestration potential is based on the results of the distribution model and rests on the following assumptions:

- Mangrove stock in 2050 and 2070: the current ratio between the total area of the potential distribution of *R. mangle* in the state to the actual distribution area in the state stays constant over time.
- The conditions for potential distribution of *R. mangle* are also adequate for other mangrove species (*A. germinans* (L.) L. and *L. racemosa* (L.) C.F. Gaertn.) and co-exist together in the same environmental conditions [29].
- Carbon sequestration: the current carbon stock per unit area of mangroves (tree plus soil) in the Mexican North Pacific region (Mg C/ha) remains the same to 2050 and 2070.

Based on this, the 2050 and 2070 distribution areas were used to estimate the corresponding total carbon stock for all projections. This was finally translated into potential CO₂ sequestered values considering the full oxidation of the organic carbon stored.

The process was implemented for every projection in the following way:

- (1) Present ratio, r : $r = \frac{\text{Actual distribution area (current)}}{\text{Potential distribution area (current)}}$
- (2) Expected mangrove area, E : $E = r * \text{Potential distribution area (future)}$
- (3) Stored carbon, S : $S = E * \text{Carbon stock per unit area reported in literature}$
- (4) Carbon dioxide sequestration potential, CSP : $CSP = S * \frac{\text{molar mass CO}_2}{\text{molar mass C}}$

3. Results

3.1. Potential Distribution Maps

A cut-off value of 0.903 for the probability of presence for all maps was used to define the presence and absence of the species. The evaluation of the map to current conditions with the Roc-Partial tool indicates that the model is adequate and statistically significant, according to the repeat count with an AUC < 1 [39].

The current conditions map of *R. mangle* for Baja California Sur has an area of 15,192 km², while almost all future projections show an increase in area ranging from 0.06% (ACCESS-CM2 SSP5-8.5 to 2050) to 56% (MPI-ESM1-2-HR SSP2-4.5 to 2070) compared to the current conditions map. In the case of the projections to 2050, all have an increase compared to the current potential distribution. But if we compare the projections to 2050 and 2070, we can observe that only ACCESS-CM2 SSP2-4.5 and MPI-ESM1-2-HR SSP2-4.5 increase their area to 2070, while the remaining projections decrease their potential distribution (for more details see Table S1). Figure 2 below shows the expected evolution of the projected surfaces to the year 2050 and 2070.

To facilitate the observation of the potential distribution maps, the different models were overlaid with the corresponding scenario and projection to 2050 or 2070 (for more details see Figure S1 and Table S2). On the other hand, all future projections for red mangrove show a northward shift of the modeled environmental conditions that are favorable to the species. The average latitudinal value at current conditions is 25.72 decimal degrees, while the lowest average displacement is 25.83 decimal degrees with the MPI-ESM1-2-HR SSP2-4.5 model at 2070 and the highest average displacement is 26.39 decimal degrees with the ACCESS-CM2 SSP5-8.5 model at 2070.

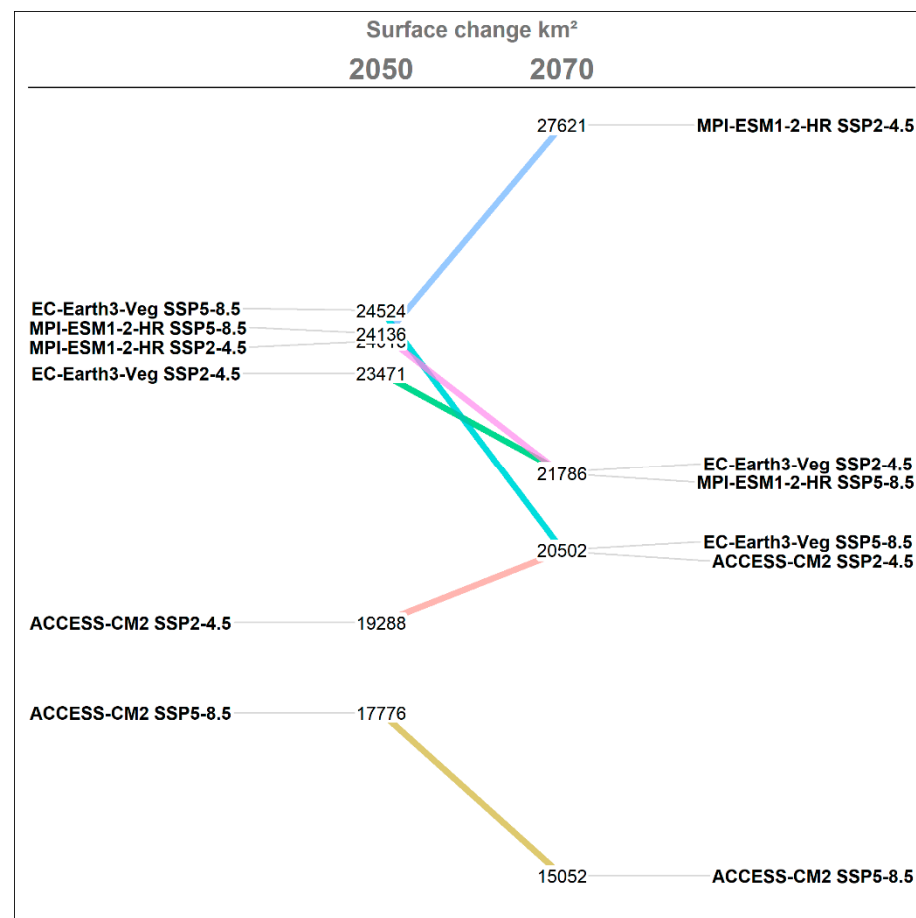


Figure 2. Changes in potential red mangrove distribution area for the state of Baja California Sur to 2050 and 2070.

3.2. Carbon Sequestration Potential

As mentioned above, the present conditions for the distribution of *R. mangle* in Baja California Sur are found in 15,192 km² (1,519,200 ha). Considering that CONABIO [41] reported an actual cover of mangroves in Baja California Sur of 25,511 ha for the year 2020, the actual mangrove cover ratio (r) equates to 0.0168 (1.68%) of the current potential distribution area. This ratio will be used to estimate expected mangrove cover (E) for all projections and subsequently calculate the potential carbon sequestration in REBIVI.

In this way, considering that the current potential distribution area for *R. mangle* in El Vizcaíno Biosphere Reserve is 6543.74 km² (Figure 3), and that North Pacific mangroves are reported to store (*Stock*) 204.9 Mg of organic carbon per hectare [42], the current potential total carbon stock (above and below ground) expected for the Reserve is 2,251,544 Mg. If fully oxidized, this results in 8,255,663 Mg of CO₂ currently potentially sequestered. Table 1 shows the potential distribution area and carbon sequestration potential of all projections to 2050 and 2070.

Under these projections, all potential and expected areas as well as carbon stock values and sequestered CO₂ in REBIVI would increase by 2050 in comparison to current values. However, these values undergo a decrease in four of the six projections to 2070. The largest reduction is found in the ACCESS-CM2 SSP5-8.5 projection with a potential distribution area 930 km² smaller in 2070 than in 2050 (Figure 4). Figures 5–7 show the potential distribution of *R. mangle* for the three General Circulation Models used.

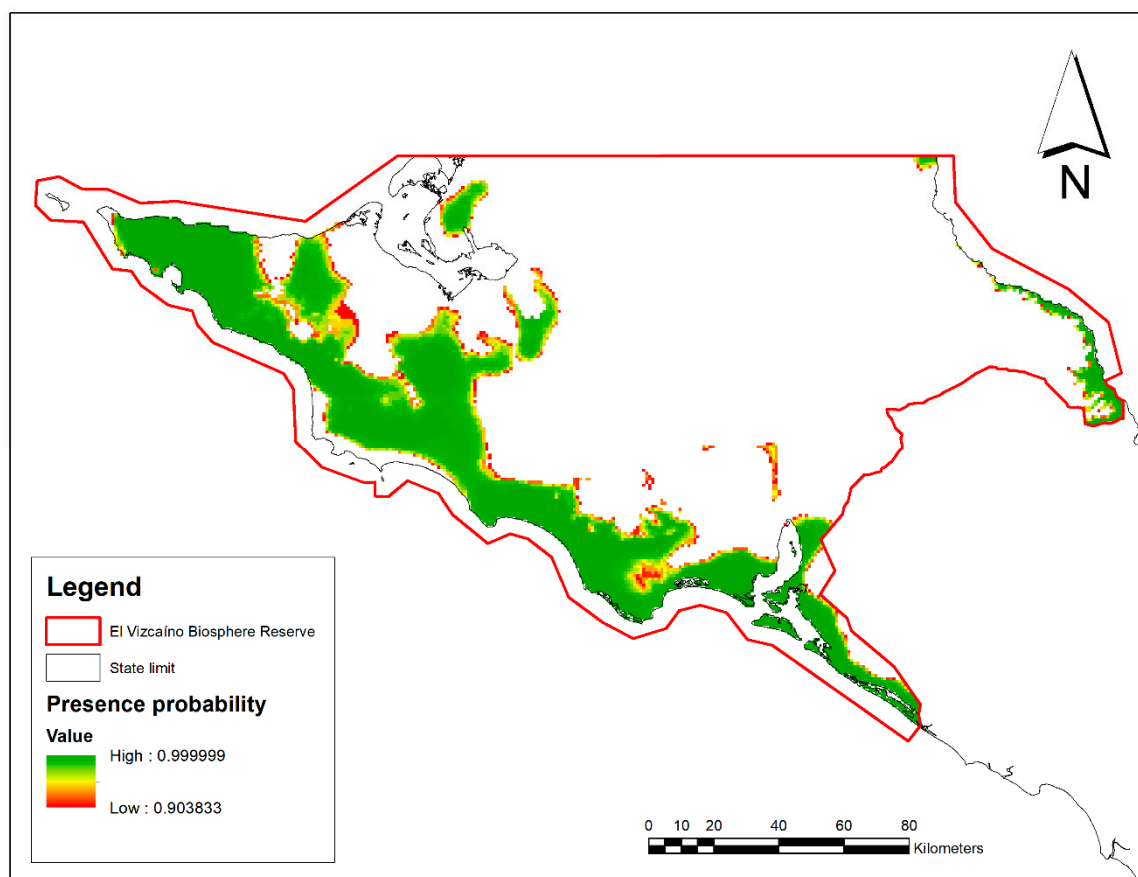


Figure 3. Current potential distribution area for *Rhizophora mangle* in El Vizcaino Biosphere Reserve.

Table 1. Carbon potential sequestration *Rhizophora mangle* in El Vizcaino Biosphere Reserve.

Projection	Potential Distribution Area (km ²)	Expected Mangrove Area (ha)	Carbon Stock (Mg C)	Sequestered CO ₂ (Mg CO ₂)
Current	6544	10,989	2,251,544	8,255,663
ACCESS-CM2 SSP2-4.5 2050	9419	15,816	3,240,756	11,882,773
ACCESS-CM2 SSP2-4.5 2070	9619	16,153	3,309,702	12,135,575
ACCESS-CM2 SSP5-8.5 2050	8996	15,107	3,095,467	11,350,045
ACCESS-CM2 SSP5-8.5 2070	8067	13,546	2,775,593	10,177,174
EC-Earth3-Veg SSP2-4.5 2050	9948	16,704	3,422,738	12,550,040
EC-Earth3-Veg SSP2-4.5 2070	9479	15,917	3,261,470	11,958,722
EC-Earth3-Veg SSP5-8.5 2050	10,159	17,060	3,495,531	12,816,947
EC-Earth3-Veg SSP5-8.5 2070	9443	15,857	3,249,042	11,913,153
MPI-ESM1-2-HR SSP2-4.5 2050	10,238	17,193	3,522,754	12,916,765
MPI-ESM1-2-HR SSP2-4.5 2070	11,115	18,664	3,824,282	14,022,367
MPI-ESM1-2-HR SSP5-8.5 2050	10,431	17,516	3,589,037	13,159,802
MPI-ESM1-2-HR SSP5-8.5 2070	9873	16,579	3,396,994	12,455,646

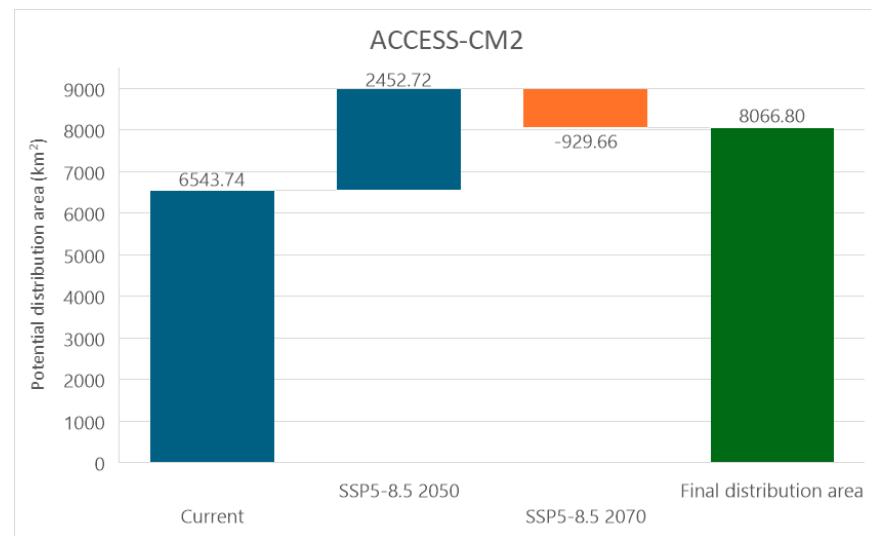


Figure 4. Evolution of the potential distribution area of the ACCESS-CM2 SSP5-8.5 models in El Vizcaíno Biosphere Reserve.

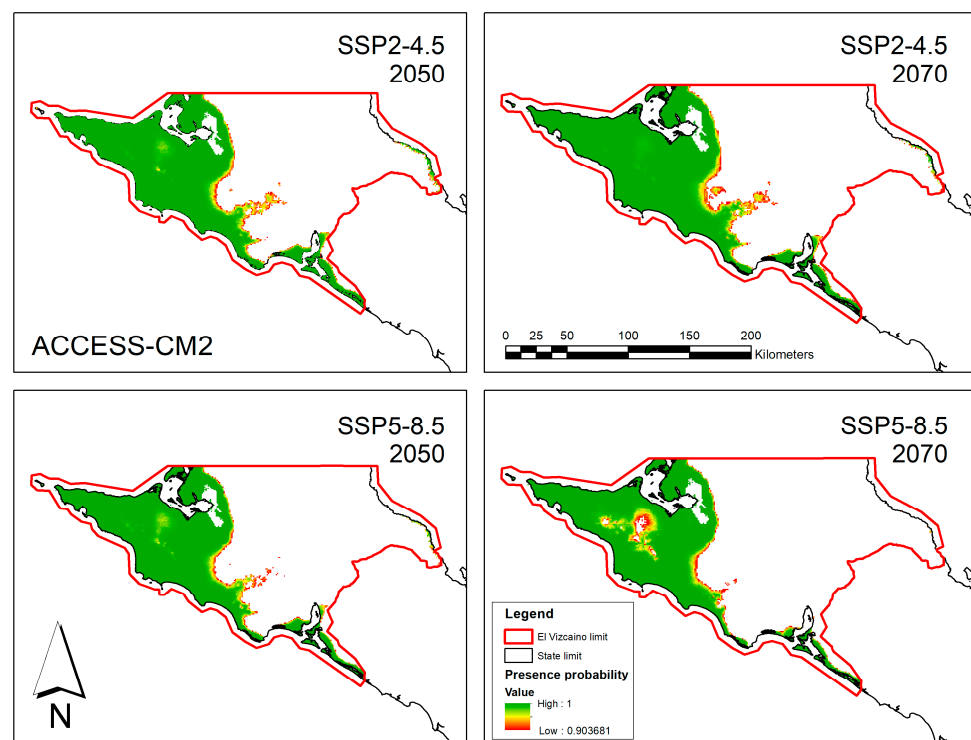


Figure 5. Potential distribution area for the ACCESS-CM2 GCM of *Rhizophora mangle* in El Vizcaíno Biosphere Reserve.

To investigate possible causes for the reduction in the potential distribution area from 2050 to 2070 in most of the projections, an analysis of bioclimatic values was performed considering their values for all projections. The analysis found that only the bioclimatic variable Bio5 (the maximum temperature of the warmest month) showed significant differences between 2050 and 2070 projections for all GCMs. Possibly these Bio5 differences caused a reduction in the area of suitable conditions for potential distribution from 2050 to 2070.

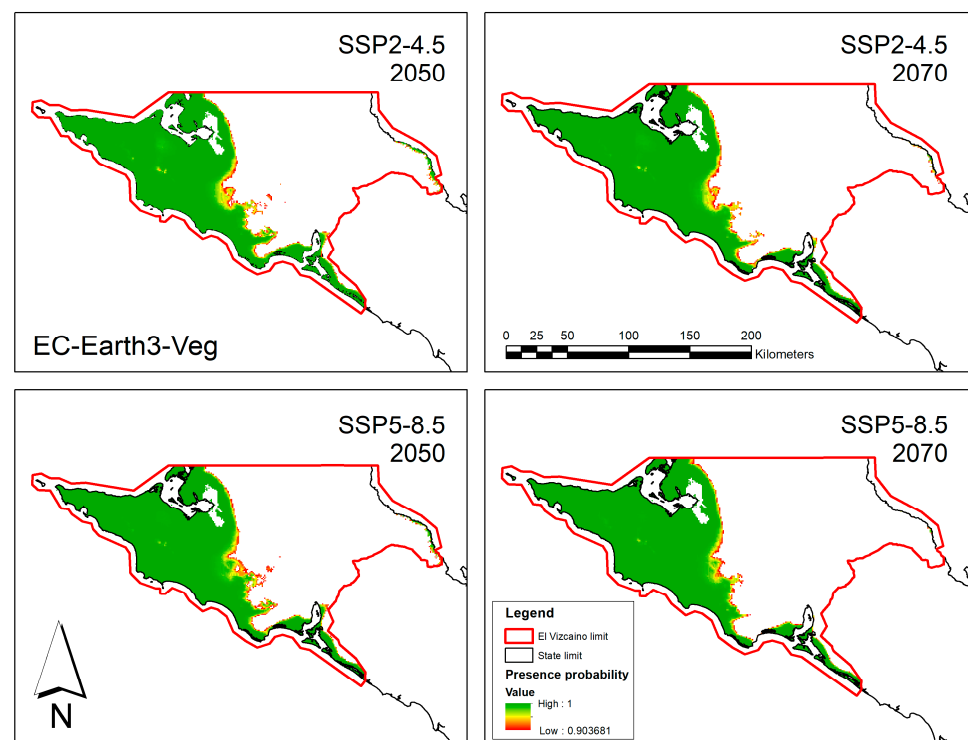


Figure 6. Potential distribution area for the EC-Earth3-Veg GCM of *Rhizophora mangle* in El Vizcaino Biosphere Reserve.

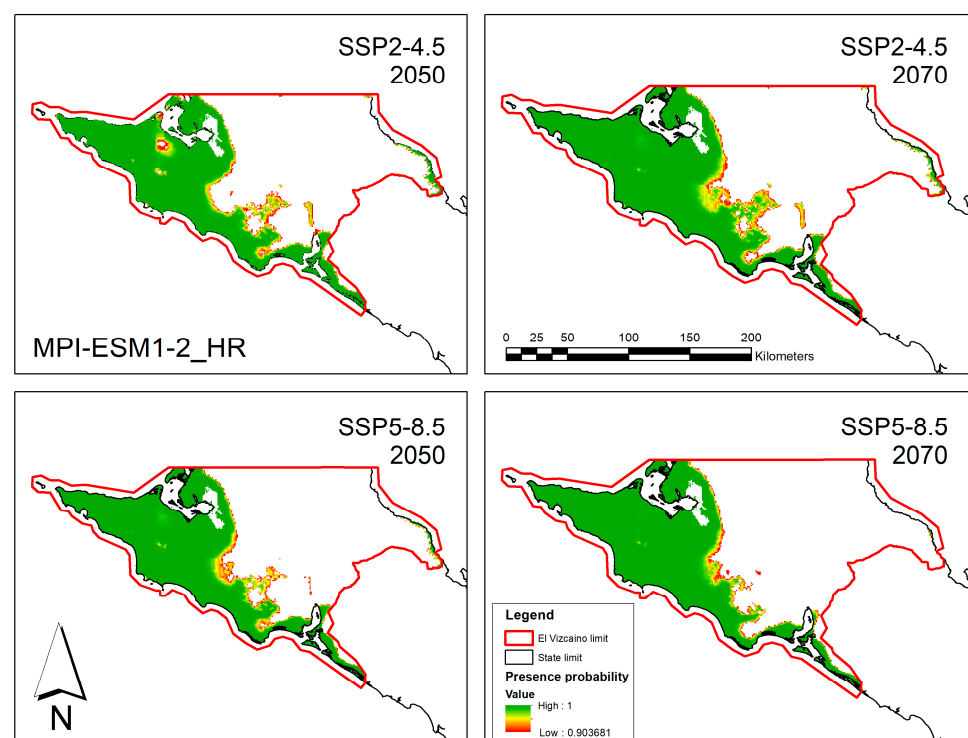


Figure 7. Potential distribution area for the MPI-ESM1-2_HR GCM of *Rhizophora mangle* in El Vizcaino Biosphere Reserve.

Finally, we compared the maximum temperature values of the warmest month in the potential distribution areas to 2050 (“projection 2050”) and the area in 2050 that no longer had suitable conditions for the presence of the species in the projection to 2070 (“Lost

2050"). In other words, we only compared the temperature values between the potential distribution area in 2050 and the same area but in the 2070 projection (Figures 8–10).

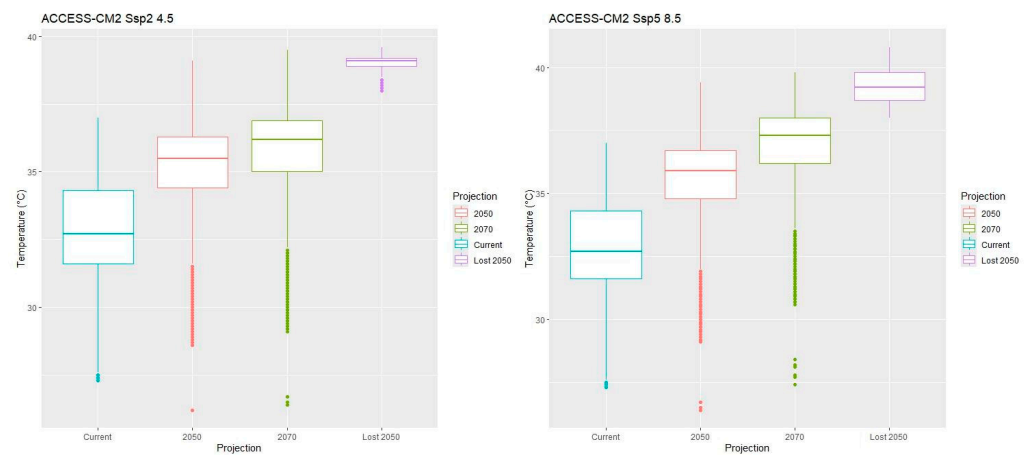


Figure 8. Comparison of the maximum temperature of the warmest month (Bio 5) between the different projections of the potential distribution of *Rhizophora mangle* for the General Circulation Model ACCESS-CM2.

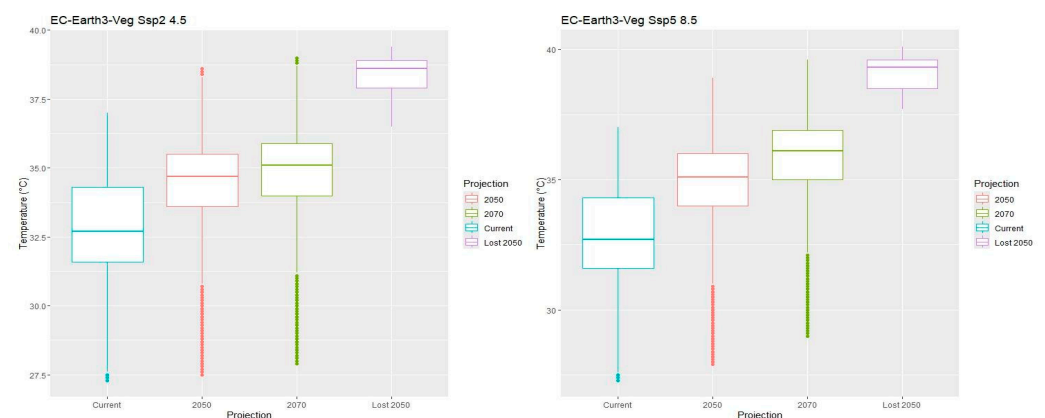


Figure 9. Comparison of the maximum temperature values of the hottest month (Bio 5) between the different projections of the potential distribution of *Rhizophora mangle* for the General Circulation Model EC-Earth3-Veg.

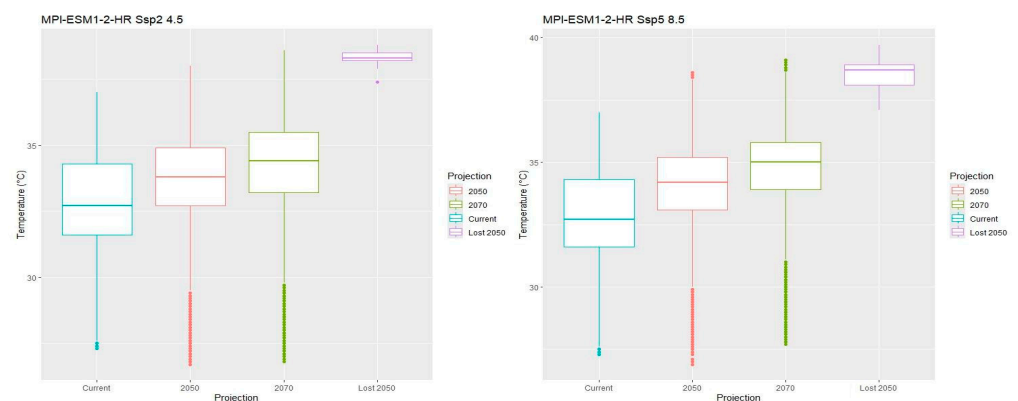


Figure 10. Comparison of the maximum temperature of the warmest month (Bio 5) between the different projections of the potential distribution of *Rhizophora mangle* for the General Circulation Model MPI-ESM1-2-HR.

4. Discussion

Our results indicate that the potential future distribution of *R. mangle* could have an increase in Baja California Sur to 2050, a reduction by 2070 compared to 2050 and a possible shift in the modeled conditions that are favorable for the species towards the north of the state. In the case of the potential distribution area of *R. mangle* in El Vizcaíno Biosphere Reserve, the results show the same pattern as for the state: an increase in the potential distribution for all projections to 2050. However, most of the projections to 2070 show a reduction in the potential distribution in comparison to their 2050 values. This has a direct impact on the carbon sequestration potential in the region. Based on the potential distribution models obtained, *R. mangle* (alongside other mangrove species in the ecosystem) could potentially capture carbon in a range from 10,177,174 Mg CO₂ up to 14,022,367 Mg CO₂ in the year 2070.

The projected future potential distribution pattern in our results coincides with that found by Record et al. [21] for the four species with current ranges limited to the Americas, western and central Africa and the western Pacific islands: *A. germinans*, *L. racemosa*, *R. mangle* and *Rhizophora racemosa*. The authors found that all four species could experience losses in total suitable coastal habitat under the future climate scenario of the National Center for Atmospheric Research's (NCAR) CCSM3 Global Circulation Model A1b scenario to 2080 compared to current climatic conditions.

In addition, they also found that the four species of mangrove already mentioned could have a poleward shift under the future climate scenario compared to current climatic conditions. Similarly, the results of Wang et al. [43] show that the northern edge of the natural mangrove distribution in China could migrate to 2050 from 27.20° N to 27.39° N–28.15° N. In addition, they also find that the total extent of suitable mangrove habitats would expand.

In the case of Cavanaugh et al. [44], their results indicate that mangroves are expanding poleward along the east coast of North America. However, the observed expansion on the eastern coast of Florida has been facilitated not by increases in mean temperature, but by decreases in the frequency of discrete cold events. Likewise, Fazlioglu et al. [45], using herbarium and human observation records, found that several mangrove species have shifted latitudinally over a 70-year period from 1950 to 2019.

In a region close to our study, the results of López-Medellín et al. [46] in Bahía Magdalena, Baja California Sur, found that during two decades of their study period, a significant area of salt flats became colonized by new mangrove growth, and a narrow association between vegetation types and flooding levels. In addition, the work of Hak et al. [47] reported a 32% increase (7575 ha) in mangrove vegetation during the period from 1986 to 2001. They mention that the most significant increase in mangrove occurred with the black mangrove-dominated stands which increased by 6056 hectares (105% increase) from 1986 to 2001. Much of this increase appeared to occur in the Magdalena Bay region.

It is clear that mangroves and many species are changing their location due to the modification of the planet's environmental conditions [48–51]. However, despite the fact that climate change will negatively affect the planet's biodiversity, it is also true that there are areas of opportunity to “take advantage” of these changes in the climate. In the case of our work, we are identifying sites where there are potential future conditions for the presence of *R. mangle* and possible carbon sequestration as the vegetation develops.

To achieve this, a proper planning of reforestation activities in the medium and long term must take place now, as it is projected that there are adequate environmental conditions for the species to establish more easily. Placing seedlings of red mangrove and other mangrove species in anticipation of possible changes in environmental conditions would not only be helping to mitigate climate change, but would also be simultaneously distributing new ecosystem services to the area. These ecosystem services could help increase the adaptation of human communities as the vegetation develops, since mangroves help support the conservation of biological diversity by providing habitats, spawning grounds, nurseries and nutrients for a number of animals [3,52].

As the sea level rises and the waves reach further inland, it could be possible to place *R. mangle* seedlings in these new areas with suitable conditions since this species can survive in sediments that are consistently inundated whereas *L. racemosa* and *A. germinans* can only tolerate short periods of inundation followed by sediment exposure and drying [53,54]. Rising sea levels as a result of climate change mean that coasts are eroding at a fast rate and storm surges are more likely to cause damaging coastal flooding. Natural coastal vegetation, such as saltmarshes and mangrove swamps can, in the right places, stabilize the shoreline and act as a buffer, absorbing the force of waves. On a natural coast, the shoreline will move inland and as the sea level rises, the coastal vegetation will gradually move inland with it [55]. However, in order to start planning these reforestations on a regional basis, several inputs are needed, mainly future projections of sea level rise and the microtopography of the land where the reforestations are to be carried out, since it is important to undertake land preparation activities to improve the survival rate of the reforestations.

It is worth mentioning that the legal aspect is an important part of the conservation and protection of vegetation in Mexico. One of the standards that most clearly specifies the specifications for the care of wetlands and mangroves in coastal areas is NOM-022-SEMARNAT-2003, which establishes the specifications for the preservation, sustainable use and restoration of coastal wetlands, including mangrove areas (the agreement that adds specification 4.43 D.O.F. 7 May 2004), published in the Official Gazette of the Federation on April 10, 2003. Likewise, NOM 059 SEMARNAT-2010 is a Mexican Standard that has the objective of listing the species or populations of wild flora and fauna at risk in our country for their corresponding care and protection, by integrating the corresponding lists [56].

Additionally, the Mexican standard NMX-AA-120-SCFI-2016, Secretary of Economy 5/86, establishes the requirements and specifications of environmental quality, health, safety and services for the sustainability of beaches in the following modalities: (1) recreational use and (2) priorities for conservation. This Mexican standard applies to persons and legal entities interested in evaluating the quality of beaches throughout the national territory (Ibid).

The absence of specific legislation for coastal and marine zones in Mexico places these fragile ecosystems, such as beaches, deltas, estuaries, tidal flats, tidal channels, coastal dunes and mangroves, wetlands, seagrass beds, reefs and others, in a situation of legal helplessness, favoring their continuous deterioration due to the poor management of the territory and its natural resources.

Finally, although it has been easier to plan and carry out conservation activities in a world with a stable climate until a few years ago [57], we need to start planning adaptation measures to cope with climate change and reduce the negative effects as much as possible. However, even though many climate change adaptation initiatives use climate-resilient infrastructure, the importance of conserving ecosystems to cope with climate change has been recognized in recent years. Ecosystems are important because they are a natural barrier against extreme events and provide goods and services that improve people's quality of life [58]. The use of ecosystems to establish adaptation measures to climate change are called Ecosystem-based Adaptation (EbA) strategies, which help to conserve, restore and sustainably manage ecosystems and natural resources [59], providing services that allow human populations to adapt to the impacts of climate change and climate variability [60].

5. Conclusions

Our results show that the environmental conditions that are suitable for the presence of *R. mangle*, both in the state of Baja California Sur and in El Vizcaíno Biosphere Reserve, will be modified in the future. The projected future potential distribution area is larger in 2050 compared to the projection under current conditions, but smaller in most projections than the projected area in 2070. This has direct impacts on carbon sequestration potentials in the region, which correspondingly increase by 2050 under all projections but that also show subsequent reductions under most of the 2070 projections.

These findings highlight the importance and urgency of acting now in order to take advantage of future expected conditions. The restoration and reforestation (including expansion) of mangrove vegetation in natural protected areas is an excellent option for establishing climate change mitigation solutions that simultaneously work as adaptation measures, strengthening these ecosystems and improving the livelihoods of local populations.

Mangrove species such as *R. mangle* can play an important role in climate change mitigation and adaptation, for instance, as part of ecosystem-based strategies. However, in order to realize this potential, the national legal and regulatory framework must be strengthened if the protection and conservation of mangroves in the state of Baja California Sur is to be successfully achieved.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/d16110660/s1>, Figure S1: Overlapping of potential distribution projections of *Rhizophora mangle* in Baja California Sur; Table S1: Potential distribution of *Rhizophora mangle* in Baja California Sur under different scenarios of climate change; Table S2: Potential distribution surface by GCMs overlapping.

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