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Development and Structural Organization of Mexico's Mangrove Monitoring System (SMMM) as a Foundation for Conservation and Restoration Initiatives: A Hierarchical Approach

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Abstract: Mangroves provide ecosystem services worth billions of dollars worldwide. Although countries with extensive mangrove areas implemented management and conservation programs since the 1980s, the global area is still decreasing. To recuperate this lost area, both restoration and rehabilitation (R/R) projects have been implemented but with limited success, especially at spatial scales needed to restore functional properties. Monitoring mangroves at different spatial scales in the long term (decades) is critical to detect potential threats and select cost-effective management criteria and performance measures to improve R/R program success. Here, we analyze the origin, development, implementation, and outcomes of a country-level mangrove monitoring system in the Neotropics covering >9000 km^2 over 15 years. The Mexico's Mangrove Monitoring System (SMMM) considers a spatiotemporal hierarchical approach as a conceptual framework where remote sensing is a key component. We analyze the role of the SMMM's remote sensing products as a "hub" of multi- and interdisciplinary ecological and social-ecological studies to develop national priorities and inform local and regional mangrove management decisions. We propose that the SMMM products, outcomes, and lessons learned can be used as a blueprint in other developing countries where cost-effective R/R projects are planned as part of mangrove protection, conservation, and management programs.

Keywords: mangroves; SMMM; remote sensing; rehabilitation; restoration; neotropics; CONABIO; SEMARNAT; Mexico; Latin America

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1. Introduction

Mangrove wetlands are not only one of the most productive coastal ecosystems in the world but also provide a wide variety of ecosystem services worth billions of dollars [1–7]. Yet, mangrove ecological importance and economic value have not always been recognized as indicated by the global area reduction in the last 40 years [8–12]. As this area loss is caused by several and distinct factors in different coastal regions, mangrove wetland Restoration and Rehabilitation (henceforth R/R; sensu [13–15]) programs have been implemented since the late 1970s at different spatial scales and following different methods and approaches [16–23].

One of the main challenges, however, to conserve, rehabilitate, and restore mangrove wetlands is the lack of long-term data and information about their structural (e.g., species distribution, root biomass, tree height) and functional (e.g., Net Primary Productivity/NPP, phenology, nutrient uptake rates, hydroperiod regimes) properties at different spatiotemporal scales. These quantitative data sets are needed to define long-term performance measures to operationally define the success or failure of R/R projects [14–16,23–25].

Historically, mangroves were not only classified as forested ecosystems but also were assumed to function as other terrestrial forests (e.g., tropical, temperate) without explicitly considering the critical ecological role of hydrology and hydroperiod in regulating mangrove distribution and production patterns in subtropical and tropical latitudes [26–28]. This initial perception, in conjunction with the lack of field data, was prevalent in early mangrove restoration initiatives in both the Atlantic East Pacific (AEP) and Indo West Pacific (IWP) regions, especially in developing nations where most of the mangrove area is found [27,29,30]. In coastal areas within those regions, it is still prevalent to use the direct planting of seedlings/propagules as a typical terrestrial forestry technique in mangrove R/R projects without considering the ecological role of hydrology/hydroperiod thus limiting project success or complete failures [14,15,31].

These negative outcomes start with the failure to explicitly consider mangroves as wetland habitats where the close interaction between anoxic soil conditions—regulated by hydroperiod—and mangrove species-specific adaptations and fertility requirements are crucial to successfully restore mangroves at the landscape level (>1 km^2) (e.g., [19,28,32,33]). This perception has begun to shift during the last 15–20 years as more studies and management programs explicitly consider the role of natural (e.g., temperature increase, tropical cyclones) and anthropic impacts (e.g., deforestation, wood extraction) on the modification of landscape-level hydrological patterns in coastal areas affected by major changes in land use and land cover change (LULCC) in the coastal zone (e.g., urban development, agriculture, aquaculture, tourism) [34,35].

These landscape-level changes are apparent when large mangrove diebacks are caused by the extensive and pervasive impact on hydrology alterations as a result of the construction of water control structures (e.g., dams) in upper watersheds, road construction along the coast, and changes in precipitation patterns induced by extreme climatic events (e.g., droughts, floods, hurricanes) among other causes. Although these wetland diebacks are not initially recognized, they became visible over several years as they expand and affect other ecological properties including biodiversity, carbon/nutrient cycling, or local fisheries, as observed in a wide range of coastal regions characterized by different climate and ecogeomorphic settings (e.g., Ciénaga Grande de Santa Martha estuarine complex, Colombia [36–38]; Marismas Nacionales, Mexico [39]; Gulf of Carpentaria, Australia [40], and the Everglades, USA [41,42]).

Given the functional role of hydrological/hydroperiod patterns regulating mangrove functional and structural properties, a major shift in spatial scale is required to explicitly consider these patterns as restoration performance measures [16]. One benefit of this paradigm shift is the explicit identification of this attribution to understand the link between water/nutrient availability and restoration outcomes (e.g., tree height, species composition) at ecological meaningful spatial scales [21,27,43–45]. This implies moving from plots with dimensions of 1–2 ha generally selected for propagule/seedling planting to areas extending several square kilometers fully restored.

This larger spatial scale is required to encompass not only watersheds controlling surface water and groundwater availability in the coastal zone, but also different geomorphic landforms (e.g., deltas, lagoons, estuaries) that control ground elevation and sedimentation input and distribution patterns [16,46,47]; together, these drivers control mangrove growth, reproduction rates, and productivity. The interaction among these environmental drivers determines the relative extent and dominance of specific mangrove species and ecotypes that define ecosystem services quality and quantity [19,35].

Remote sensing studies are one of the upper-level scale approaches globally used to cover extensive areas at different resolutions and to determine mangrove aerial changes since the late 1970s [34,48–53]. There has been, however, a lack of spatially explicit, systematic, and comprehensive temporal assessments linking those studies to explain differences in functional connectivity across regional and local scales, and that are needed to develop efficient long-term monitoring efforts [34,54,55]. As mangrove area declines or is degraded, it is apparent that local studies (e.g., biomass and forest density/mortality studies) which obtained most of the cases separately from remote sensing assessments, need to be used to inform the analysis of data and information at large scales by promoting the participation of local stakeholder/researchers to maximize the acquisition of field data [56]. This is a key phase to identify and monitor outcomes in R/R project based on initial priorities and objectives in adaptative resource management and conservation projects, as well as being critical for other inland and coastal wetlands (e.g., marshes, seasonally flooded forest, gallery forest, cypress forests) that are hydrologically coupled to mangrove-dominated ecosystems undergoing large-scale human impacts and restoration efforts in subtropical and temperate regions [57–62].

In this work, we describe and analyze the origin, development, implementation, selected results, and strengths/weakness of one of the first and lasting mangrove monitoring system—"Sistema de Monitoreo de los Manglares de México" or SMMM (Spanish acronym; Mexican Mangrove Monitoring System)—in the Neotropics. This system explicitly considers a spatiotemporal hierarchical approach as a conceptual framework when remote sensing is one of the major components at the sub-continental scale [63–66]. We consider this system as an example of the application of new science-policy models to fill a critical need to increase the utility of science for management and decision making (i.e., translation science [67,68]) that facilitates the coproduction [56] of data and information by different scientific disciplines and stakeholders to improve management decisions [69].

Among the main objectives of the SMMM is the implementation and validation of cartographic information to improve mangrove protection and conservation programs and help in the implementation and evaluation of R/R projects in Mexico. The SMMM encompasses the total mangrove area in Mexico (patches > 1 hectare), which represents 6.7% of the global mangrove area (i.e., 137,600 km^2) [8]. Indeed, Mexico's mangrove area (9051 km^2 [63]) is second to Brazil (8% 11,072 km^2) [8], which has the largest mangrove extension in the AEP region. Moreover, as mangroves expand poleward from subtropical to temperate latitudes due to climate change [70], those countries' boundaries typify the current location of the ongoing mangrove migration occurring in the northern (e.g., Baja California, Mexico) and southern (e.g., Santa Catarina, Brazil) [71–73] hemispheres in the Neotropics.

In this paper, we analyze the approach and path followed by the Mexican Government —focused on the SMMM—to manage and protect mangrove wetlands and to explore its potential utilization as a template or "blueprint" in other countries in Latin America. Especially in countries attempting to advance the protection and management of their mangrove resources using a science-based approach with the explicit collaboration among federal, state, academic institutions, and stakeholders [74–80]. The specific objectives are to: (1) describe the implementation and development of a monitoring mangrove system to inform—at the country-level—the status on mangrove natural resources management within an ecogeomorphic hierarchical approach and (2) analyze the role of remote sensing products by the SMMM as integrator or "hub" of multi- and interdisciplinary ecological and social-ecological studies to: (a) support the developing of national priorities and (b) guide and inform local and regional mangrove management decisions for mangrove protection, conservation, and management policies.

We first briefly describe the spatial hierarchical conceptual framework used to develop the SMMM and Mexico's geography characterized by the diverse coastal environmental settings that determine the distribution and extension of mangrove wetlands controlled by a wide range of climate zones and coastal geomorphic landscapes. We then define the SMMM's monitoring components and some specific products along different stages during system development from 2005–2020. We also analyze some of the specific findings at different spatial scales that illustrate the need to identify major differences in mangrove functional properties along distinct environmental settings. These are represented by the interaction of eco-geomorphology and species/ecotype dominance that can help in identifying management decisions, for example, in hydrological-based restoration/rehabilitation initiatives. Due to the SMMM program which is structured as a science-based initiative using an adaptative approach, e.g., [81], we also include some examples of the ecological studies that inform the implementation and analysis of different remote sensing products as part of that adaptative perspective. We end with a description of the strengths/weakness and their implications to further consolidate and advance the SMMM mission, particularly in the case of mangrove R/R projects.

2. Materials and Methods

2.1. Area Description

Mexico is a megadiverse country located among the Eastern Pacific Ocean (EPAC), the Caribbean Sea (CS), and Gulf of Mexico (GOM) basins (Figure 1A). The country has a complex orography (Figure 1B) that results in a wide range of different types of terrestrial and aquatic ecosystem hosting ~10% of the planet's endemic species [82,83]. The wide range of climates (e.g., Hot Desert, Tropical and Subtropical Steppe, Wet Equatorial) (Figure 1C) and ecoregions (Mediterranean California, Great Plains, Tropical Moist Forests) (Figure 1D), geomorphology (tectonic, depositional, volcanic), and biogeographic history facilitates the establishment and development of highly productive and biodiverse ecosystems [84,85]. Due to the major differences in regional geological origin and orography, the precipitation patterns and associated runoff is variable between the EPAC and GOM basins [86–91]. The high elevation and variable slope across mountain ranges (Figure 1B) close to the EPAC, strongly influence the coastal and inland local/regional weather and climate patterns including the seasonal impact of tropical cyclones (Figure 1E) [90,92]; these natural disturbances have a major regulatory control of mangrove successional patterns, total biomass, and carbon storage aboveground in mangroves, e.g., [93,94].

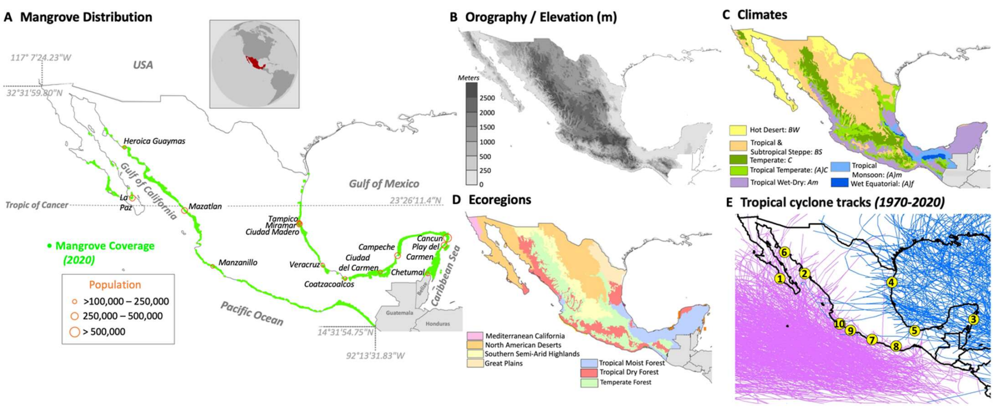

Figure 1. (**A**) Mangrove wetland distribution [95] and coastal populations centers (>100,000) in Mexico [96]; (**B**) orography and relative elevation (m) [97]; (**C**) climate classification regions [98]; (**D**) Ecoregions [99]; (**E**) tropical cyclones' trajectory and density in the Atlantic (blue color) and Pacific basins (pink color). The top ten landing sites are shown in decreasing order per state: 1: Baja California, 2: Sinaloa, 3: Quintana Roo; 4: Tamaulipas; 5: Veracruz; 6: Sonora; 7: Guerrero; 8: Oaxaca; 9: Michoacán; 10: Colima [90,92].

In addition to Mexico's total mangrove area (Figure 1A), the SMMM target area also encompasses a strip or "buffer" adjacent to the mangrove wetlands to identify and characterize other types of vegetation and to classify the type of drivers causing LULCC [100]. This total area was delimited using the following criteria: (1) a 5 km buffer band next to the mangrove area or patches; (2) mangrove sites where both natural resources/biodiversity and rehabilitation projects are planned or undergoing; (3) presence of Natural Protected Areas (i.e., ANPs, Áreas Naturales Protegidas in Spanish) [101]; (4) presence of Ramsar sites [102]; (5) an elevation boundary of 50 m using a Digital Elevation Model (DEM) [103], and (6) the original National Institute of Statistics and Geography (INEGI) mangrove coverage datasets (Series I [104]). The ANPs' GIS polygons were used in the SMMM initial area delimitation since they represent an official administrative landscape unit where several natural resources management and conservation projects are undergoing. However, both the ANPs and Ramsar sites were included only when at least 80% were present within the area boundaries. The DEM was applied in coastal mountainous regions while the INEGI Series I was used to evaluate historical changes in the mangrove area [105].

The largest mangrove area in Mexico is in the GOM and Caribbean Sea (6397 km^2) when compared to the EPAC (2653 km^2) [65] (Figure 1A). Although the total area is the second largest in the Neotropics, the species diversity is low (n = 6) when compared to other countries in the IWP region (n = 17 [30,106]). These species are: *Rhizophora mangle*, *Rhizophora harrisoni*, *Laguncularia racemosa*, *Avicennia germinans*, and *Avicennia bicolor*. The mangrove associate *Conocarpus erectus* and *Conocarpus erectus* var. *sericeus* are also found in limited locations. *R. mangle*, *L. laguncularia*, and *A. germinans* are widely distributed along the GOM/Caribbean Sea and EPAC coastlines; the species *A. bicolor* and *R. harrisoni* are restricted to the EPAC along the coastal zone of the state of Chiapas [107–110]. The total mangrove area along Mexico's coastline (i.e., 12,122 km) is bounded by the coordinates 29°23′55″ N, 14°31′43″ S, −87°11′59″ E, and −113°44′35″ W with variable coverage in all 17 coastal states [92] (Figure 1A).

2.2. Hierarchical Conceptual Framework and CONABIO Coordination

Although not explicitly included during the SMMM planning phase, a conceptual hierarchical approach (hierarchy theory, e.g., [111–113]) continues to be integrated into the system to advance the conceptualization based on the combination of a mangrove wetlands hydrogeomorphic classification [114] and a typology of geomorphic and sedimentary coastal settings [16,32,115] (Figure 2). This hydrogeomorphic classification explicitly considers hydrological and ecological functional properties that are typically found in the AEP and reflected on the different mangrove physiognomies (sensu [114]) (see Section 3.2.1) characterized, for instance, by different vertical structure and growth form. Thus this classification is operatively useful to perform comparative mangrove ecological assessments among countries within the AEP region, especially in remote sensing studies [116–118].

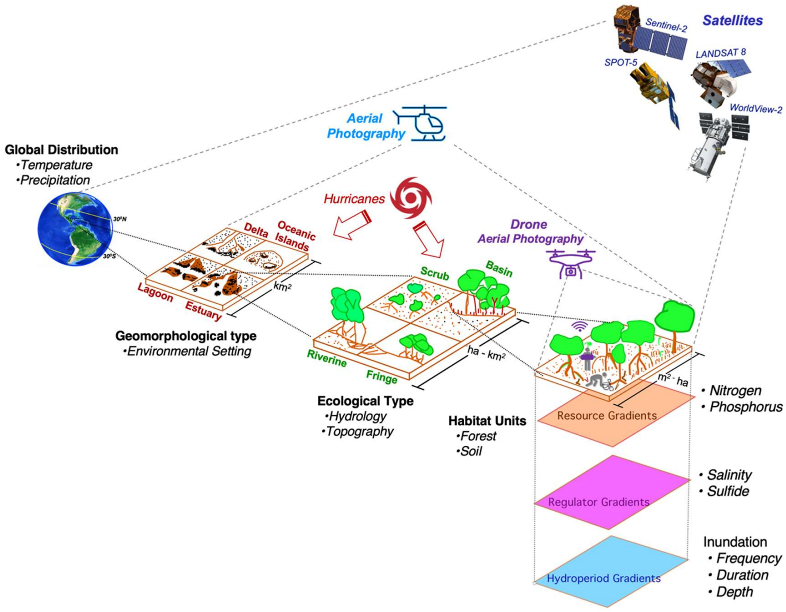

Figure 2. Hierarchical classification for mangrove-dominated ecosystems describing abiotic controls on mangrove structural and functional properties at the global (temperature, precipitation), regional (geomorphology), and local scale (ecotype habitats) in the neotropics. Environmental factors in each spatial-level control processes determine soil properties, fertility gradients, and mangrove productivity.

Remote sensing coverage and aerial photography are also shown at different spatial scales (modified from [16]). Satellite photo credits: SPOT-5 image credit: CNES [119]; Sentinel-2 [120]; LANDSAT 8 [121]; WorldView-2 [122].

The combination of both classifications (i.e., hydrogeomorphic and typology) facilitates an operational linkage between local and regional spatial scales allowing an explicit linkage among forest structure/function, regional environmental settings, and climate (precipitation, temperature); the interaction among these variables is reflected overall in six distinct mangrove ecotypes including riverine, basin, fringe, scrub, overwash, and hammock ("Peten" [123–125]) at the local scale [126] (Figure 2). Hence, the need to explicitly incorporate a hierarchical classification of spatial scales and associated processes to identify the relative role of an array of drivers—from the global distribution of mangroves (i.e., temperature and precipitation) and the development of different geomorphic settings [127]—to the colonization of those settings by different mangrove ecotypes that respond to diverse gradients in nutrients (resources), salinity (regulators/stressors), and hydroperiod (frequency, duration, and depth of inundation) (Figure 2) [16].

This spatially explicit approach to synthetize the complex range of environmental variables regulating mangrove structural (e.g., tree height) and functional (e.g., biomass, carbon storage) attributes can be directly coupled to remote sensing analysis (Figure 2). For instance, by combining the wide range of spatial resolution of optical, radar and LiDAR measurement, it is now possible to reduce the uncertainty when "upscaling" representative field-based measurements [34,43,54]. One example is the determination of tree height in the field that is used to calibrate LiDAR data acquired at both regional and global scales, and then used to convert height measurements to biomass units to assess aboveground carbon storage at the continental level [44,45,128–130] (Figure 2). Accordingly, the combined use of remote sensors with high and medium spatial resolution (e.g., SPOT-5, Sentinel-2, Landsat 8, WorldView-2) and field data that explicitly identifies the regulatory effect of stressors, resources, and hydroperiod on mangrove structure/productivity, represents a significance advance to understanding the attribution of both ecological and socioeconomic factors impacting mangrove area loss or recovery and revealed by the availability of ecosystem services [4,34,131].

2.3. Remote Sensing and Field Data Collection and Cartography

Since 2005, five periods have been evaluated and monitored by the SMMM: 1970/1980, 2005, 2010, 2015, and 2020 (Figure 3). The SMMM cartographic mangrove area baseline—including adjacent non-mangrove areas—was defined in 2005 using SPOT 5 images as well the cartographic data for 2010 and 2015 (Figure 3, Table 1). The cartography in 1970/1980 was produced in collaboration with the National Institute of Statistics and Geography (INEGI, acronym in Spanish; Figure 3, Table 1). The most recent 2020 cartography was produced using Sentinel-2 images because at the beginning of 2015, the SPOT-5 satellite was decommissioned, and the optical characteristics of its successors did not meet the technical requirements that the SMMM needed to assess mangrove area changes (Figure 2, Table 1). The technical satellite images descriptors used in the SMMM program represent one of the key aspects to maintain a coherent method to warrant comparability among maps produced in different dates. The optical characteristics offered by Sentinel-2 images are very similar to those presented by the SPOT-5 images since both sensors provide information on the Near Infra-Red (NIR) and Short Wave Infra-Red (SWIR) bands, which are needed for the identification of mangrove vegetation [63]. In addition, Sentinel-2 images have two SWIR spectral bands that allow better identification of mangrove vegetation unlike SPOT-5, which only had one. Further, Sentinel-2 SWIR bands have been used regularly in the differentiation of mangroves and other vegetation [52,132–138].

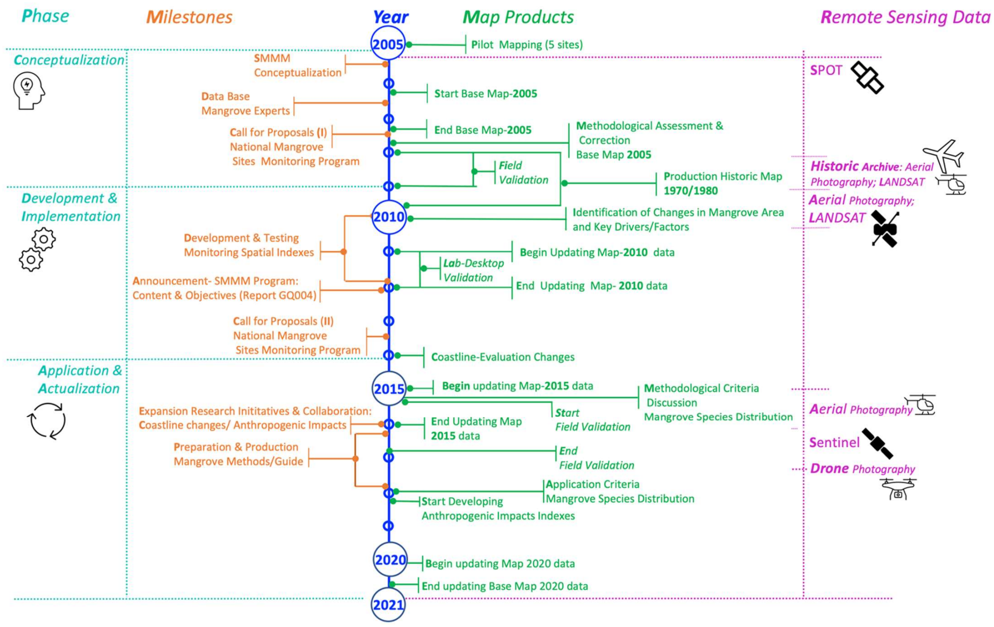

Figure 3. Different phases and milestones in the development of the Mexican Mangrove Monitoring System (Spanish acronym: SMMM) from 2005–2020 including the production of maps and analysis of remote sensing data.

Table 1. Description of materials used to produce the original SMMM cartography from 1970–2020. D/A = do not apply; (N*) = number of images/data sets; INEGI: Instituto Nacional de Estadística y Geografia.

Year	Data Availability (N*)/Type	Remote Sensing Band ID Combination	Band Resolution (m)	Data Acquisition Date	Sampling Frequency (Days)	Data Source	Data Availability	Data Source		Classification Methods	Validation Materials	Cartographic Accuracy
								Advantages	Disadvantages			
1970/1980	Historical aerial photographs archive (1505); **Landsat TM** and MSS (46); 17% study area coverage	D/A	D/A	1970–1985 (most area coverage is for 1981)	D/A	INEGI	D/A	Best historical data sets availabile	Photopgraphs spatial coverage is limited	Retrospective Comparative Interdependent method ([139])	Validation was not perfomed	Not performed due to lack of data
2005	**SPOT 5** (134); **Landsat ETM** (2)	B3/4/2	10	2005 & 2006 (82% area coverage) 2003, 2004 & 2007 (18% area coverage)	26	SPOT 5: CNES 2003, 2004, 2005, 2006, 2007 Produced by SIAP under "SPOT IMAGE" licensing	Licensing required (use/acqusition)	Infrared shortwave band (SWIR) highlights soil and vegeation humidity	Difficulty in including all study area for one single year analysis due to image quality	No supervised classification; "Isodata" iterative algorithm ([140])	69,000 aerial vertical photographs from helicopter; altitude, 150–200 m; Secretary of the Navy	Accuracy 92.8% ([39])
2010	**SPOT 5** (174)	B3/4/2	10	2010 (80% area coverage) 2009 & 2011 (20% area coverage)	26	SPOT 5: CNES 2009, 2010; Produced by SIAP under "SPOT IMAGE" licensing	Licensing required (use/acqusition)	Infrared shortwave band (SWIR) highlights soil and vegetation humidity content	SPOT 5 ancillary information have spectral and spatial resolution differences	Retrospective Comparative Interdependent method ([139])	5300 aerial vertical photographs from helicopter; altitude, 150–200 m; Secretary of the Navy	Accuracy: 92.4% ([39])
2015	**SPOT 5** (182; 93% study area coverage); **SPOT 6** (4); SPOT 7 (2); RapidEye (10)	B3/4/2	10	2014 (last 3 months) 2015 (63% area coverage)	26	SPOT 5: CNES 2014 & 2015; Produced by SIAP, under "SPOT IMAGE" licensing;	Licensing required (use/acqusition)	Infrared shortwave band (SWIR) highlights soil and vegeation humidity	Infrared shortwave band (SWIR) is absent	Retrospective Comparative Interdependent method ([139])	62,000 aerial vertical photographs from helicopter; altitude, 150–200 m); Surveillance V2; Secretary of the Navy	Accuracy: 93.4% ([39])

Table 1. *Cont.*

Year	Data Availability (N*)/Type	Remote Sensing Band ID Combination	Band Resolution (m)	Data Acquisition Date	Sampling Frequency (Days)	Data Source	Data Availability	Data Source		Classification Methods	Validation Materials	Cartographic Accuracy
								Advantages	Disadvantages			
2020	**Sentinel-2** (102)	B8/11/4 RGB combination	10 [Bands 11 & 12 were reprocessed using "super-resolution" to obtain a 10 × 10 m pixel size]	2020 (January–May)	5	Europe Space Agency (ESA)	Free distribution and direct downloading from ESA website	The total study area coverage occurs in 5 months; satellite passage resampling period is short; improves boundaries definition	Need to adjust differences in the classification of "other vegeation" and "agriculture/livestock" classes	Retrospective Comparative Interdependent method ([139])	Aerial vertical photographs taken with a fix-wing drone; altitude, 100–200 m; UASMEXICO Survelliance V2	Accuracy: 94.86% ([unpublished]

To visualize the mangrove mapping images, a combination of the bands NIR (B8), SWIR1 (B11), and Red (B4) were assigned in the respective RGB channels; this band arrangement is consistent with previously used imaging display. Although the data input changed, the same visualization method was maintained to allow a comparison among maps/dates [63].

Given the need for systematic information for the validation of remote sensing data, mangrove sites were established in different mangrove ecotypes and geomorphic settings to sample mangrove structural variables (e.g., density, basal area, canopy height, species composition, biomass) and productivity in different coastal regions using the same methodology (Figure 4); some environmental variables (e.g., soil pore water salinity, organic matter, pH) were also measured. A key aspect in this experimental design was to select a plot area (~400 m^2) that would match, as much as possible, the pixel spatial resolution from satellite images. A total of 319 plots distributed among 10 coastal states were established with a minimum of 12 plots per site/state (range: 12–57) to warrant statistical replication in the EPAC, CS, and GOM basins (Figure 4; see Table S1: Projects/field sampling reports). These sites were established in two phases during the program implementation (2007, 2013; Figure 3).

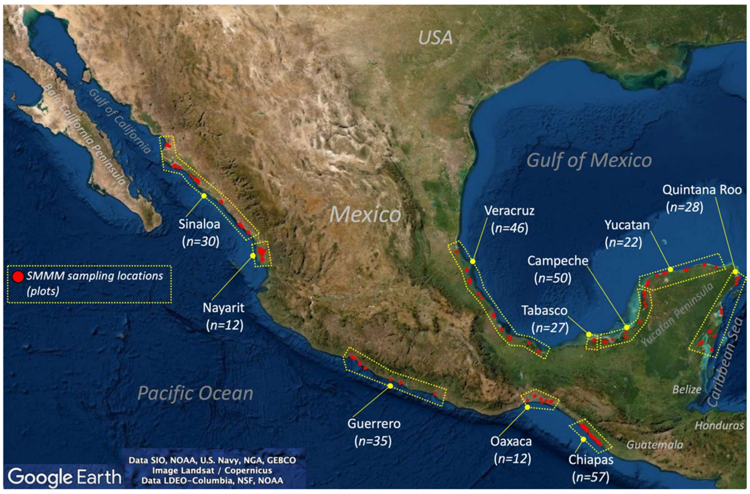

Figure 4. Location of sampling sites per coastal state (not to scale) where monitoring plots (400 m^2) were deployed in ten coastal states in the Eastern Pacific Ocean, the Caribbean Sea, and Gulf of Mexico basins; n = number of plots per state. See Table S1 for weblinks to data and information about geographical coordinates and mangrove forest structural data.

2.4. Data Processing

Here, we only explain the method implemented to produce the most recent cartography in 2020. The Sentinel-2 satellite images were resampled using the 20 m pixels of the SWIR bands at 10 m using the tool Super-Resolution [133,141] and the open source software SNAP, developed by ESA [63].

We also used the interdependent interpretation method proposed by FAO [139] to produce the cartography for selected dates. The exception was the 2005 map when we used an unsupervised classification iterative "isodata" algorithm [140] (Table 1). The use of the interdependent method helps to keep all maps comparable and reduce errors derived from false readings (omission/commission errors) [142]. The 2020 cartography update was produced using the 2015 data as a base map where mangrove patches and other land classes were modified by visual interpretation according to the changes registered in the 2020 satellite images. The cartographic scale used in the SMMM is 1:50,000 and a minimum mapping unit of 1 ha based on nine vegetation and land use categories [105] (Table 2).

Table 2. Description of classes used in the SMMM to produce the cartography of both mangrove and adjacent land cover [105].

Class	Description
Mangrove	•Arboreal and scrub mangrove vegetation composed of one or mix-species including *Rhizophora mangle* (red mangrove), *Avicennia germinans* (black mangrove), *Laguncularia racemosa* (white mangrove); *Avicennia bicolor*; *Rhizophora harrisoni*; *Conocarpus erectus* (mangrove associated).
Disturbed mangroves	•Dead arboreal and scrub/shrubby mangrove vegetation or areas undergoing regeneration; includes mangrove impacted by tropical storms and hurricanes and antrophic infrastruture (hydraulic structures; highways, roads).
Other wetlands	•Hydrophitic vegetaton (Popal-Tular-Carrizal; [143]), grasslands subjected to flooding, other hydrophitic or halophitic vegetation types that include dispersed individuals or isolated mangrove patches/grooves; coastal saline terrains with sparse non-mangrove vegetation.
Anthropic development	•Settlements, aquaculture ponds; shrip farms; salt flats; roads and highways; and hydraulic infrastructure including channels.
Crops/Cattle Grazing	•Land used for agriculture (rainfed and irrigation); grasslands used for animal husbandry activities; land used for food production; regional perennial tree monocultures and other agroecosystems including nomadic agriculture.
Unvegetated	•Apparent unvegetated and eroded areas; coastal sand dunes; beaches.
Other vegetation types	•Perennial/subperennial flooded low/mid elevation tropical forests; shrubby and arboreal secondary vegetation; herbaceous secondary vegetation.
Water bodies	•Ocean, bay, estuaries, lagoons, rivers, reservoirs, sink-holes (i.e., Cenotes), water holes.
Others	•Surfaces covered by clouds/cloud shadow.

3. Results and Discussion

3.1. Program Development (2005–2020)

The SMMM was created and funded by the Mexican government in 2005. This program explicitly acknowledged the biocomplexity of different ecological processes occurring at different spatial scales and the complex multi-variable impacts of human activities on mangrove ecosystems services. Given the increasing synergy of both human activities and climate change threats along Mexican coastal regions—including increasing sea level rise and air temperature and reduced water availability—the original program aimed to providing up-to-date data and information for planning, policy development, and management decisions (e.g., [144]. In fact, the SMMM was initially considered a project oriented to produce cartographic products, but eventually it became a system where several components needed to advance mangrove conservation and protection initiatives at the national level. Thus, not only national trends in mangrove area loss and gains are assessed, but also the degree of socioeconomic activities impacting mangrove functional properties along the coastal zone. These properties were readily recognized as ecosystem services of national interest including provisioning (e.g., genetic, fisheries), regulating (climate, water quality, natural hazard regulation), cultural (recreation, ecotourism) and supporting (blue carbon, productivity, water storage) ecosystem services [145,146].

The SMMM program is housed and coordinated by the National Commission for the Knowledge and Use of Biodiversity (CONABIO, Spanish acronym; https://www.gob.mx/conabio, accessed on 17 March 2022) [147]. CONABIO is a Mexican inter-ministerial commission whose mission is to promote, coordinate, support and perform activities aimed at assessing the knowledge of biological diversity. CONABIO's philosophy is based on producing knowledge supported by the best possible scientific information for the conservation and biodiversity sustainable management [147–151].

One of CONABIO's main goals is the creation and development of the National System of Information on Biodiversity (SNIB, Spanish acronym) that aims to gather, analyze, and produce information and knowledge about biodiversity and natural capital in Mexico [150]. The SNIB is integrated by four components: (1) information on species (registry of specimens, observations, catalog of taxonomic authority and biological data of the species); (2) geographic information and geomatics tools for spatial analysis and monitoring (cartography and remote sensing data); (3) computer tools and developments for data management and information synthesis; and (4) a national and international network of scientists who participate in the study of biodiversity, and who provide and review SNIB information [148]. Based on CONABIO's mission and SNIB structure, the SMMM program was then operationally divided in three phases: conceptualization, implementation, and application (Figures 3 and 5). The conceptualization phase lasted from 2005–2009 when the main structure of the system was established following CONABIO main objectives. At this stage, a directory/database of national and international mangrove ecology experts was compiled and simultaneously began the analysis of mangrove wetlands spatial distribution using SPOT-5 products end eventually complemented with structural data obtained from the network of field sites as information was analyzed over time (see Section 2.3; Figure 4).

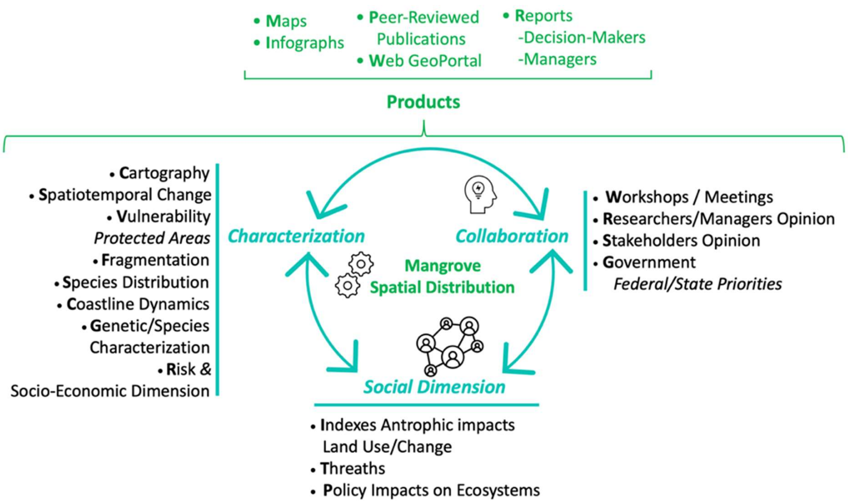

Figure 5. Interaction among the different phases included in the Mexican Mangrove Monitoring System (Spanish acronym: SMMM) and specific products based on the evaluation of the periodic mangrove spatial distribution assessment (see Figure 3).

One key component triggering a comprehensive spatial coverage and high-resolution mapping was the involvement of the Secretaría de Marina that contributed (in-kind) equipment and technical support for the use of helicopters (altitude: 150–200 m) thus enhancing field validations, resolution, and accuracy in the mangrove boundaries/area delimitation. The main products from that first comprehensive survey were the preparation of a base map (scale 1:50,000) using 2005 data followed by the production of a historic mangrove map 1970/1980; Table 1). For the first time it was possible to identify historical changes in mangrove area (mapping down to 1 ha) and key drivers of change at the national level. This mapping effort help to identify up to 81 mangrove locations considered of key biodiversity priority, including sites where mangrove R/R projects were needed [65].

In the development and implementation phase (2010–2014; Figure 3), monitoring spatial indexes were tested to facilitate the transfer of information to summarize data for management decisions and assessments of potential risk; particularly for areas where major changes in mangrove area were identified. A second call for proposals was also issued to expand the national mangrove sites monitoring program (Figure 3); in this call the main objective was to establish areas in the northern coastal states and other coastal states not previously included in the analysis. The main map products in that period were an update of the 2010 mangrove cartography and major advances in the analysis of key remote sensing products.

The application and feedback phases are continuous process involving the production of updated mangrove maps every five years (Figures 3 and 5). Additionally, we have expanded research initiatives and collaborations with more national and international institutions (Figure 6) that are not only interested in the use of SMMM products, but also in advancing some of the emerging research questions identified by the monitoring activities (see study cases below). Based on the SMMM cumulative experiences, a methods document was prepared for research and education purposes [65,152] (Table S1). In this phase the effort was focused on assessing net changes in coastline area and the development of criteria to map mangrove species distribution at different scales that could be produced using Sentinel-2 and WorldView-2 products (Figures 2 and 5). One current objective is to produce anthropogenic impact indexes to help visualize and inform local and regional stakeholders when implementing management decisions [153]; especially when gauging the size and type of mangrove R/R projects that might be needed.

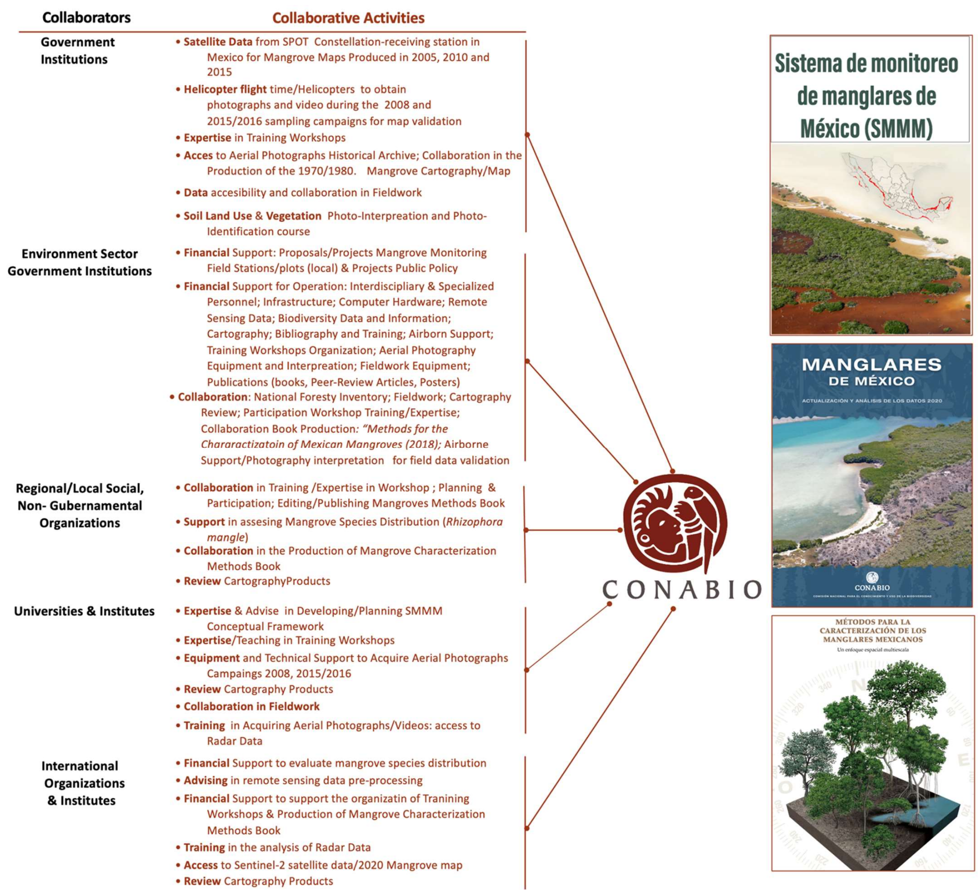

Figure 6. List and interactions among different collaborators in the Mexico's SMMM showing key activities developed and implemented from 2005–2020.

Thus, the SMMM is an iterative process in the assessments of mangrove natural resources that is centered in the evaluation of spatial trends (Figure 5). Based on funding availability and logistic constraints, this system attempts to maintain a constant flow of data/information across the assessment, characterization, collaboration, and social demands/requirements that are re-evaluated according to new priorities and needs.

3.2. Selected Case Studies Based on SMMM Research and Management Priorities

3.2.1. Spatiotemporal Changes (2015–2020) in Unimpacted and Disturbed Mangrove Extension and Uncertainty in the Assessment of Scrub Mangrove Ecotype Area

Overall, mangrove wetlands represent ~0.46% of Mexico's total area (1,972,550 km^2) [154]. Using remote sensing data nine classes were defined to evaluate temporal changes in the EPAC, CS and GOM coastal regions (Figures 1A and 7A–F). The mangrove area estimated in 2020 (905,085 ha) shows a net area gains (129,530 ha) from 2015 (775,555 ha) representing a 16.7% increase [63]. This increment, however, cannot be considered as mangrove recovery or gain, but an improvement in the spatial analysis using higher resolution remote sensing products combined with further field validation (e.g., local expert opinion). One example derived from this technical improvement is the identification and classification of the scrub mangrove ecotype. This ecotype, characterized by low stature as result of low nutrient availability [155,156] or hypersalinity [157] among other factors is dominant in large coastal areas under arid climate in the northern EPAC (e.g., [158]) and in karstic regions throughout the CS [156]. The latter is the case of the Sian Ka'an Complex (state of Quintana Roo) (Figure 7C) where 83,791 ha comprises this characteristically low stature ecotype (mean tree height < 3 m). This new assignation has legal implications as the new reported areas promptly become protected under legislation already in place at the state and federal level.

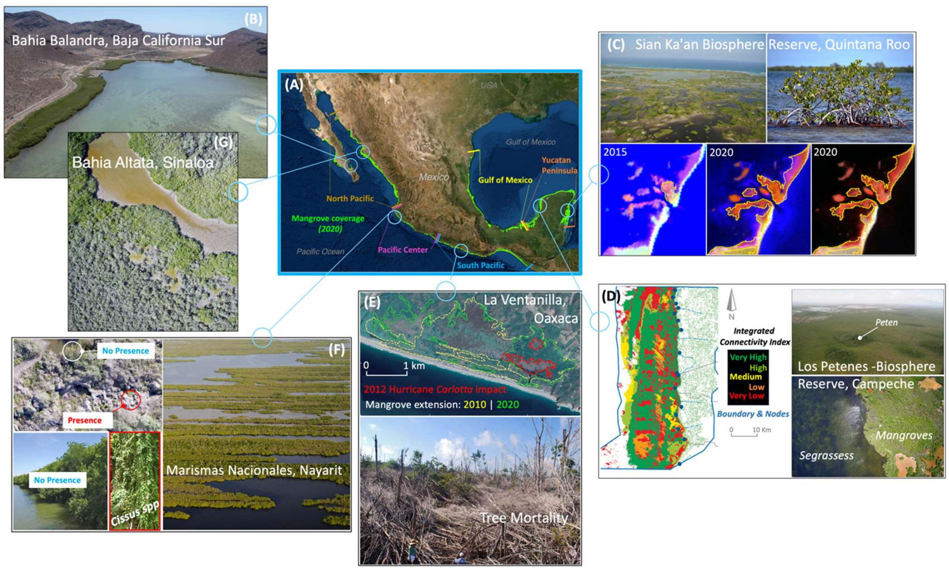

Figure 7. Selected study cases in different locations and Mexican states along the Pacific and Gulf of Mexico coasts as part of the SMMM; Map sources: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community (**A**), which is integrated by the North, Center and South Pacific regions and the Yucatan and Gulf of Mexico regions; the boundaries among these regions are marked by perpendicular colored lines. (**B**) mangrove distribution in semi-arid regions, Bahía Balandra, Baja California Sur (photo credit: C. Troche); (**C**) spatial analysis of scrub mangrove forests, Reserva de la Biosfera Sian Ka'an, Quintana Roo (photo credits: left, O. Ortiz; right, A. Alcántara); the second row panel shows images depicting different bands combinations (left to right): B3, B4, B2 (2015, Spot, CNES); B8, B11, B4 (2020): ESA, Copernicus Space Component); B8, B11, B12 (2020): ESA, Copernicus Space Component); (**D**) Connectivity analysis between mangroves and sea grasses in Reserva de la Biosfera Los Peténes, Campeche (photo credits: above, M.T. Rodríguez; below J. Díaz; (**E**) Mangrove mortality caused by hurricane "*Carlotta*" in La Ventanilla, Oaxaca (photo credit: C. Tovilla); (**F**) phenological analysis of the species *Rhizophora mangle* impacted by invasive species (presence; *Cissus* spp.) in Marismas Nacionales, Nayarit (photo credits: upper and below left: A. Alcántara, right E. Villeda; *Cissus* spp. photo source: Forest & Kim Starr: http://www.starrenvironmental.com/imageusepolicy/, accessed on 17 March 2022; (**G**) Mangrove

distribution along the semiarid coastal region of Bahía Altata, Sinaloa (photo credit: A. Segovia). See results and discussion section for each study description and objectives. Photos, maps and figures credits: [63]. The cartographic (shape files) and remote sensing images metadata are available in the CONABIO portal: https://biodiversidad.gob.mx/monitoreo/smmm; accessed on 17 March 2022.

Further, the incorporation of free/open source processing tools to analyze large historical databases available in the cloud, along with the analysis of satellite images and other geospatial data such as Google Earth Engine® (GEE, Google Inc., Mountain View, CA, USA) have facilitated the analysis of vegetation indices (e.g., NDVI) [159–163]. These additional tools are advancing the construction of time series analysis of mangrove phenology to help corroborate the re-classification of mangrove areas (e.g., [164]).

In contrast to the increase of healthy mangrove areas classified using spectral signatures (e.g., Normalized Difference Vegetation Index, NDVI) [54,63], areas classified as "disturbed mangrove" decreased by 47% from 2015 (18,332 ha) to 2020 (9680 ha). The use of this class is critical when evaluating landscape-level changes in mangrove area and their potential drivers. This "disturbed" category was operationally defined based on its conspicuous spectral signature using an NDVI, which was closely associated to a range of both anthropogenic and climatic disturbances at a regional scale (i.e., defoliation, tree mortality, deforestation) (Figure 7E). This class is considered "transitional" since it represents major shifts from other LULCC categories (e.g., urban development; agriculture-livestock husbandry) including their return to the "healthy" mangrove class relative to the surrounding mangrove forest stands' status. This mangrove recovery depends on the original natural or human disturbance magnitude and frequency in combination with the resilience capacity regulated by the environmental setting, original mangrove ecotype composition, and spatial distribution; the area, for example, reclassified from "disturbed mangrove" to "mangrove" from 2015 to 2020 was 5093 ha [63]. The sites where this "disturbed" category is spatially extensive are selected, depending on funding availability, for further forest functional and structural characterization to track vegetation changes [64].

Further, the analysis of the shift in mangrove extension using the nine mangrove categories defined in the SMMM (Table 2) is facilitated by the use of a visualization tool that serves not only as an analytical but also as an educational tool (i.e., Atlas de Naturaleza y Sociedad; ANS, Spanish acronym; see Table S1). The ANS is a combination of physical/human geography data and a computer interface that assists in the evaluation of chronological changes in the mangrove area associated to the diversity of human impacts at the local, regional, and country level.

3.2.2. Assessing Mangrove Species Distribution and the Impacts of Invasive Species

Results from this study show the successful collaboration among different partners participating in the SMMM (Figures 5 and 6). Funding, for example, from the David & Lucile Packard Foundation, initially was focused on the evaluation of mangrove area extension dominated by the species *R. mangle*. Given *R. mangle* phenology and tree architecture, this species of monospecific forest located along the intertidal/subtidal zone provides critical zones for commercial and local fisheries providing reproductive habitats, food, and shelter [165,166]. Thus, they represent a valuable resource in the Marismas Nacionales coastal system [165] (Figure 7F), Nayarit. In this project, *R. mangle* monospecific forest stands were identified from other mix-species forest stands using WordView-2 images at high spatial resolution (1.6 m). By using vegetation indexes and Landsat 8 images time series analysis (30 m spatial resolution), it was feasible to obtain valuable information for a detailed phenology analysis of *R. mangle*. Due to the successful classification, this approach—using a combination of sensors that included Sentinel-2 images—was applied in five other study sites in Northwestern Mexico (Sinaloa, Sonora y Baja California Sur; Figures 2 and 7B,G).

Due to the spatial resolution applied when characterizing mangrove forest monospecific stands in the above mentioned project, it was also evident that mangrove canopies in Marismas Nacionales were negatively impacted by a woody vine (*Cissus* sp.; "*buzzard gut*"), which is considered an invasive species [63] (Figure 7F). This vine extensively covered forest canopies that negatively interfered with photosynthesis thus causing extensive tree mortality. Both the level of impact and persistence were visible and quantifiable using a combination of remote sensing tools and field validation; this information can be used for informing management plans (e.g., mechanical removal) to avoid the spread of *Cissus* sp. to avoid further mortality and promote mangrove survival and associated net productivity. The causes promoting the vine reproduction and growth rates are currently unknown; further research is needed to assess several potential mechanisms including changes in climate, nutrient availability, and change in water/soil salinity regimes.

3.2.3. Hydrometeorological Disturbances Impacting Mangrove Structure and Function

Tropical cyclones are one of the most extensive natural disturbances impacting coastal regions in both the EPAC and GOM regions (Figure 1E). Previous studies show that cyclones can globally regulate both mangrove biomass and productivity [43,93,94], particularly in Mexico [90,92]. Thus, using the Google Earth Engine®, the SMMM will be monitoring and analyzing changes in phenology and forest structure to assess mangrove ecological resilience and resistance, including the potential recovery rates expected in R/R projects. Although field damage assessments have been performed using limited field data after storm impacts [167], this research focus within the SMMM needs expansion and financial support given the potential increase of storm frequency under a changing climate [90,106,168,169].

3.2.4. Evaluation of the Forest Crown Structure

The use of radar data to evaluate mangrove forest structure is one the most recent applications implemented in the SMMM given the spatial resolution (i.e., Sentinel-1 carrying a single C-band synthetic aperture radar instrument) and utility to estimate mangrove biomass changes using time series [132,135]. Since tree height can be used to determine aboveground biomass using allometric equations (e.g., [43]), this represents a promising application to evaluate functional attributes (e.g., NPP, carbon storage, and sequestration) at large temporal scales, especially when attempting mangrove resilience to hurricane impacts [25,94,137,170] (Figure 7E). Still, the use of radar sensor requires extensive field validation given Mexico's complex coastal geomorphology and the wide range of local fertility and stressor gradients (Figure 1B,D,E) [143,171,172].

3.3. Selected Case Studies Associated to Long-Term Assessments and Adaptive Management

3.3.1. Coastline Dynamics

Assessing mangrove spatial distribution linked to changes in coastline extension represents one of the key SMMM products contributing to understanding the functional connection between geomorphology and mangrove ecological attributes. Previous coastline maps, produced over a span of 50 years (Figure 3) [173,174], are now valuable baseline data to determine current and future changes associated to sediment transport, hydrology, and the negative impact of sea-level rise. The latter is one of the potential threats to mangroves, not only in Mexico, but globally, as a result of interaction between climate change and increasing human impacts on coastal regions in subtropical and tropical latitudes [144,175–177].

Using both historic photographic and satellite data sets, it was possible to determine a retreat of ~600 m of mangrove front allowing the delimitation of a buffer boundary for mangrove protection between the coastline and higher elevations inland. This information has been used in combination with other methodologies such as the Digital Shoreline Analysis System (DSAS) [174,178,179] to define nationwide coastline stability assessments. As part of the monitoring activities, we further use the relative location and extension of mangrove wetland boundaries using a set of permanent perpendicular transects in several regions to determine potential threats associated to erosional processes caused by both natural (hurricanes, sea-level rise, ocean currents) and human (e.g., urban/industrial infrastructure) disturbances. This analysis is performed every five years and represents baseline data at the local level to design coastal protection initiatives. Changes in hydrology at the watershed level, for instance, have already produced major alterations associated to sediment transport and deposition in both estuarine and coastal areas [174]. Thus, forecasting how mangrove spatial distribution and biomass are affected by erosional and depositional processes along the watershed and coastlines is one of the research areas that needs further development in the SMMM [66].

3.3.2. Connectivity

Coastal anthropogenic activities, including urbanization and agricultural expansion/intensification, are becoming major threats to biodiversity and associated to landscape fragmentation; this process drives both habitat (e.g., area reduction) and connectivity loss (e.g., reduction in plant and animal dispersal patterns among remnant patches) [180–182]. As hydrology is the main driver regulating and linking blue carbon wetlands (i.e., mangroves, sea grasses, coral reefs) [3,32,33,183–185], their vulnerability is becoming a major management issue as a result of direct changes in estuarine hydrological patterns and wetland hydroperiod at different scales (Figure 7D) [186]. Therefore, one of the objectives of the SMMM is to quantitatively evaluate connectivity among ecosystems and habitats to project eventually future changes in biocomplexity, biodiversity, and ecosystem services using remote sensing tools, and robust integrative indexes. For example, one of this index is the Integral Connectivity Index (IIC) [187] currently developed as part of the open source Conefor software [188,189] (http://www.conefor.org/sourcecodes.html, accessed on 17 March 2022).

The IIC is a landscape metric that integrates habitat extent and connectivity between habitat patches and is presently used to evaluate the structural connectivity between mangroves and seagrasses to inform landscape conservation planning [188]. This type of comprehensive analysis within the SMMM is helping to characterize potential risks caused by anthropogenic impacts on mangrove resources that can lead to increasing area loss and enhance vulnerability at the landscape level [63]. Moreover, these results can identify areas where mangrove R/R projects could be successful. The application and evaluation of this approach will be implemented in selected locations where biological connectivity among mangroves–seagrasses–coral have been recognized as high priority—i.e., Reserva de la Biosfera Los Peténes, Campeche—based on current environmental impacts [186,190,191] (see location in Figure 7D). Based on the results from this ongoing project [63], the application of the IIC index will be expanded to other coastal regions covered by the SMMM, to analyze blue carbon ecosystem connectivity.

3.3.3. SMMM Contribution to Implementation of R/R Projects: Social Dimension

One of the main objectives of the SMMM is to produce data and information needed to plan and rehabilitate mangrove functional properties aimed at mangrove ecosystem services sustainability (Figure 5). Yet, we recognize that this management strategy requires long-term ecological research projects, which in turn require long-term financial support. Thus, the SMMM in collaboration with universities, and federal and state institutions tasked with the mission of protecting and maintaining mangrove resources, established the network of monitoring sites beginning in 2007 (Figures 3 and 4). These sites have provided information to evaluate not only functional and structural mangrove wetland properties, but also to define performance criteria to gauge the successes of R/R projects within local and regional, environmental and climate conditions and constraints (e.g., [31,186]) (Table S1).

In combination with remote sensing assessments, these monitoring efforts have identified the extension of human impacts across areas currently considered as a conservation priority. For example, at the local scale, there are 32 settlements with ~400 people living inside mangrove wetland area; yet, when the entire SMMM mangrove target area is considered—including the buffer area (see area description section)—6,621,030 people are estimated and distributed in 7509 settlements that represent 5.2% of the total Mexico population [192]. When this population is compared to estimates in 2005 (5,187,131), when the SMMM started (Figure 3), then an increase of 1,433,908 people is apparent in the last 15 years. This increasing population density represents a challenge in the protection and conservation of mangroves in Mexico.

Although most of this new population do not live inside mangrove wetlands, their living activities affect those wetlands directly (i.e., pollution) and indirectly (e.g., changes in hydrology around wetlands due to road/house construction). Using an anthropization index, we were able to evaluate this increasing impact during that 10-year period; based on an overall aerial extension, the dominant LULCC is dominated by human settlements and the establishment of aquaculture farms and artificial ponds [63]. These types of activities are similar to the human impacts also detected in other mangrove locations around the world [29,193].

Thus, several sites—in combination with remote sensing base maps—have been identified for future R/R activities (e.g., Figure 7E) [63]. One of these efforts is led by the National Forestry Commission of Mexico (CONAFOR, Spanish acronym; https://www.gob.mx/conafor, accessed on 17 March 2022) to allocate resources from the environmental compensation program. Both CONABIO and CONAFOR, along with a group of experts, established environmental and social criteria (e.g., land ownership verification, owner commitment to project goals, inclusion of persons/groups triggering the original negative impacts) to implement mangrove R/R projects based on the type of impacts and pressing threats (e.g., [31,143,194]), which include alterations in hydrology and the increasing expansion of agriculture. This site selection also included Ramsar designed sites [195,196].

As previously mentioned, another key objective of the SMMM is to advance translational science [67] and the coproduction [56] of knowledge as related to mangrove conservation and management in Mexico. Thus after data sets are curated and validated, they become available to help to produce information and knowledge to advance educational and scientific initiatives based on stakeholder priorities. These resources are available in the CONABIO web portal, which is updated on a regular basis as the data and information is validated and published in different formats (e.g., brochures, reports, scientific papers) and media (e.g., video, photographs, computer interface visualization). The information about these resources and weblinks are listed in Table S1.

3.4. Opportunities and Challenges to Advance and Consolidate the SMMM

The SMMM became a major opportunity to bring together stakeholders, Mexican government institutions, and academia (Figure 6). This synergy (i.e., coproduction) has provided data and information that are required to evaluate historical changes in mangrove area trends to address management issues associated to conservation and restoration initiatives that are supported by law enforcement. The field validation of the 2005 base map, for example, was based on the participation of mangrove experts; they trained CONABIO personnel in cutting-edge mangrove ecological theory/knowledge while researchers benefited by participating in the aerial helicopter surveys (Figure 2) that help to validate criteria, and test assumptions and perceptions about habitat connectivity at larger spatial scales (Figures 3 and 7).

The close interaction between scientists and CONABIO remote sensing experts also accelerated the interpretation of aerial photo analysis to build databases for mapping purposes. The in-kind contribution of helicopter flight time by the Secretaría de Marina since the inception of the SMMM in 2005 was vital to cover large spatial extensions at high resolutions to cross-reference field and remote sensing data at different altitudes (Figure 3). Training also benefited undergraduate and graduate students in Mexico and international scholars who have extensively participated in field data acquisition and validation (Figure 6). The publication of thesis and peer-review papers have strengthened different stages of the SMMM further enhancing the product's scientific validity based on the monitoring program data (Figure 5). Further, educational materials (i.e., books, videos, posters, factsheets) (e.g., [197]) produced at different stages of the SMMM have successfully informed and educated stakeholders and the public (Table S1); this interest is gauged by CONABIO website visits and information requests at the local and regional level. Although the international collaboration has been limited—particularly in Latin America—there has been some exchange of experiences with the National University of Costa Rica and Colombian institutions to advance an initial framework for educational, technical, and scientific cooperation focusing on the exchange of knowledge and experience in the use, for example, of radar and optical satellite data [43,198].

The SMMM has also strengthened mangrove wetland legal protection initiatives by providing baseline data. Certainly, both the legal norm NOM 059 SEMARNAT issued in 2010 [199] and the General 2000 Wildlife Law [200] with its 60TER modification in 2007 are currently the main legal tools used at the national level to protect mangroves against removal/deforestation or indirect negative impacts (e.g., pollution). For instance, changes in mangrove area over time produced by the SMMM provided key evidence demonstrating the continuous removal of mangrove wetlands surrounding the Carpintero's Lagoon in the Northeastern state of Tamaulipas [201]. In this case, the Mexican Supreme Court used this data to stop this action and order the implementation of a rehabilitation project in areas already negatively impacted using an argument of violation to principles of prevention, precautionary and human rights to a healthy environment [202].

Unfortunately, there is still a wide range of human impacts that have accelerated the mangrove vulnerability and risks of permanent loss. This is despite institutional collaboration/coordination and data availability to stakeholder and state and local agencies in charge of protecting mangrove resources. Further work is needed, not only in enforcing laws protecting mangroves, but also effectively translating technical/scientific information to define the current and future negative economic impact of mangrove wetland loss to local communities in the long term [39,203].

3.5. SMMM Development and Implementation: An Estimated Monetary Cost

Most of the challenges to advance mangrove resources conservation and management in Mexico resemble issues faced by other developing countries in the AEP region, which host ~25% of the mangrove global area [8,11,48,193,204]. Current trends in developing countries show a decrease in the rate of loss in Asia and Africa, yet there is an increase in the rate of loss (12,650 ha/year) in the AEP region [204,205]. Indeed, each country has different challenges based on existence/absence of government and public institutions that can potentially advance mangrove conservation programs at the national level. Although the initial monetary investment in developing countries to maintaining a program like the SMMM might be considerable, we argue that its utility and long-term benefits greatly offset that investment.

In the case of the SMMM, financial resources have been allocated from different government institutions over time and are therefore associated to budgetary constraints; thus, it is difficult to establish or set an initial figure (Table 1). However, we estimate that approximately USD 2,344,190 have been injected in the program over the 15 years since its inception; this amount is allocated to efforts in establishing a monitoring network of sites (47%) and to cover operational expenses (53%) to developing the system; this includes expenses incurred in several workshops and training courses that represent a direct investment and in-kind contributions by several government institutions (Figures 3 and 6). In addition to the allocation of CONABIO's own funds to developing the SMMM, other federal institutions have provided funding including: Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT), Secretaría de Marina (SEMAR), Comisión Nacional de Áreas Naturales Protegidas (CONANP), and the Instituto Nacional de Ecología (INE) (Figure 6).

Perhaps one of the best examples underscoring the investment benefits in the SMMM creation and operation associated to a cost-effective mangrove monitoring program at the national level, is the current interest in acquiring accurate and robust field data to gauge mangrove carbon storage/sequestration capacity, which is being translated to dollars (i.e., carbon credits [206,207]) in the context of climate change mitigation efforts [6]. Despite the recognition of mangrove wetlands as carbon sinks since the late 1990s, it was not until the last 12 years that this ecosystem service [7,208,209] has become a major research priority at the global scale given the interest in developing carbon markets [210,211]. Due to current undergoing efforts to produce this mangrove carbon storage and sequestration assessments for coastal wetlands at the global scale [71,212,213], it is expected that, in the case of Mexico [206,207,214–216], the SMMM will become a critical tool to evaluate carbon storage as an ecosystem service. This assessment is required to be able to participate in future financial markets needed to sustain international efforts in climate adaptation and mitigation programs. This requires not only the validation of carbon storage inventories but also the stocks of long-term assessment and sustainability in the next decades.

However, to correctly gauge the social and economic value of mangrove resources at the national level, all mangrove ecosystem services—in addition to carbon storage and sequestration—need to be considered in the integration of this natural capital into national economic policies; these services include the provision of habitat and food for commercial and small-scale fisheries, coastal protection against storm surge and sea-level rise, water quality, and ecotourism, among others. Just in the case of fisheries in Mexico, mangrove economic value sustaining this service have been valuated at USD 37,500/ha (e.g., [217]) in the northwestern region, which is a coastal region with a semi-arid climate and exposure to major tropical cyclone impacts [92,158]. This valuation under this environmental setting underpins the diverse and direct role of mangrove wetlands in the national economy. Thus, it is expected that the SMMM would continue to provide data and information on the ecological and economic importance of mangrove wetlands, especially the selection of performance criteria to warrant successful mangrove wetland R/R projects.

4. Final Remarks and Conclusions

The SMMM is currently a critical component in the protection, management, and conservation of mangrove wetlands in Mexico. Although ecogeomorphic studies began to be published since the late 1960s in several coastal regions (e.g., Grijalba-Usumacinta Delta, Tabasco, Mexico [218]), it is not until the 1980s [110,219,220] when more comprehensive mangrove structural and functional studies began to be recognized as critical knowledge to protect and manage mangrove wetlands in Mexico [221]. This recognition was based on acknowledging mangrove species as foundation species that provide key ecosystem services of national importance including artisanal and commercial fisheries and coastal protection. Still, it is only in the mid-2000s that a government institution such as CONABIO began to develop and implement a nationally focused mangrove monitoring system. As a result of the cumulative experiences of 15 years of operation and consolidation, the SMMM's philosophy is based on the natural resource management principle stating that it is less expensive to conserve mangrove wetlands and their ecosystem services in the long term than to rehabilitate or restore them.

Accordingly, the SMMM has focused on combining the use of remote sensors (optical, radar, LiDAR) with high and medium spatial resolution, and the integration of novel technologies such as Google Earth Engine to elucidate the spatial distribution and forest structure (e.g., density, biomass, species distribution) and degree of human impacts. This information is necessary to advance, for example, the analysis of mangrove wetlands as carbon sinks/storage, evaluate long-term changes in mangrove phenology, and assess mangrove natural regeneration and the successful expansion regeneration of mangrove areas where R/R projects are undergoing or planned.

Further, the SMMM was built as a science-based initiative (i.e., hierarchy analysis/adaptive management) interacting with an array of diverse government institutions sharing the same goal. The role of CONABIO as a "hub" in coordinating the SMMM has proven effective and durable, partially due to its mandate and mission at the national level. As CONABIO was explicitly established to act as a "bridge" among research/educational and government institutions and stakeholder/society, the exact replication of this working structure might not be possible in other countries, particularly in the AEP region. Yet, we believe that institutions with similar government mandates regarding mangrove conservation and management could adapt the main SMMM's objectives to maximize and optimize existent government administrative units and infrastructure to help advance a large-scale, long-term mangrove monitoring system. This is a viable alternative, when considering already existing remote sensing expertise and institutions in charge of inventory/mapping of natural resources at the national scale in some continental regions (e.g., Central and South America)—this is how the SMMM emerged in Mexico.

It is difficult to establish a precise dollar value to develop a program such as the SMMM at the national level given the complexity of the 'in-kind'/matching of intra- and interinstitutional financial resources and participation of government agencies, institutions, and universities (Figure 5). However, it is evident that the increasing frequency and expansion of natural and human impacts on mangrove resources call for a large-scale effort for their conservation, therefore underscoring the urgency of financial investments in this type of integrated monitoring systems at the regional and country level. The assessment of mangrove ecosystem services' monetary value has improved as mangroves are further recognized, for example, as a major component in climate change mitigation programs given their carbon storage capacity (i.e., "Blue Carbon"), and other types of services including coastal protection as sea level continues increasing (e.g., [144]), and the provision of food reflected in several fisheries of vital social and economic importance to local communities (e.g., [217]).

Similar monetary valuation has been performed in other countries by focusing on single mangrove ecosystem services, but it is the compounded value that is critical for the implementation of programs such as the SMMM when a cost/benefit perspective is adopted to incentivize mangrove resources conservation at large spatial scales. This type of economic analysis—i.e., national and regional—is not yet available in the case of Mexico. However, it is evident that an investment in the SMMM implementation represents a small fraction of the overall benefits that are generally observed in other mangrove-dominated coastal regions.

It is recognized that the investment in restoration of altered/highly impacted coastal ecosystems compared to the ecosystem services' monetary value they provide is generally unbalanced in the short term. This is because a large investment is needed when implementing large R/R programs—but readily lost—if the continuing investment to keep a monitoring effort and maintenance of restoration infrastructure is not explicitly defined at the outset. For instance, an initial investment of ~35 million dollars has been practically lost when the largest (~335 km^2) mangrove hydrological restoration project in the Neotropics did not include specific resources to maintain infrastructure (channel dredging) (Cienaga Grande de Santa Marta [75,222]). Within 8 years of project implementation, the gains in mangrove area previously lost to soil hypersalinity regimes began to fall back to pre-project environmental conditions, further compounding any possibility of recovery in the short term [19,36].

Indeed, the investment needed in coastal and wetland restoration programs can tax national economies. In developed countries across temperate latitudes, for example, restoration project costs can range from USD 200 million to 50 billion, which are needed over a period of 20–50 years (e.g., [223–225]). As developing countries lack resources to implement these types of projects—at the scale and cost required in the long term—it is a fundamental strategy to avoid negative impacts on wetland ecosystems, including mangroves, in the first place. To do so requires a monitoring strategy at different spatial scales to timely identify potential problems and inform management and policy decisions before costly and drastic changes occur. Moreover, as they become irreversible, the probability of permanently losing valuable ecosystems and their services dramatically increases [226,227]. In this context, we believe that Mexico's SMMM program products, outcomes, and lessons learned—as limited in time and scope—can be used as a blueprint in other developing countries where cost-effective R/R programs are planned as part of mangrove protection, conservation, and management of the most productive coastal ecosystem in the world.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f13040621/s1, Table S1: Mexico's Mangrove Monitoring System (SMMM) weblinks: current products by category.

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References

1. López-Angarita, J.; Roberts, C.M.; Tilley, A.; Hawkins, J.P.; Cooke, R.G. Mangroves and people: Lessons from a history of use and abuse in four Latin American countries. *For. Ecol. Manag.* **2016**, *368*, 151–162. [CrossRef]
2. Costanza, R.; de Groot, R.; Sutton, P.; van der Ploeg, S.; Anderson, S.J.; Kubiszewski, I.; Farber, S.; Turner, R.K. Changes in the global value of ecosystem services. *Glob. Environ. Chang.* **2014**, *26*, 152–158. [CrossRef]
3. Himes-Cornell, A.; Pendleton, L.; Atiyah, P. Valuing ecosystem services from blue forests: A systematic review of the valuation of salt marshes, sea grass beds and mangrove forests. *Ecosyst. Serv.* **2018**, *30*, 36–48. [CrossRef]
4. Worthington, T.A.; Andradi-Brown, D.A.; Bhargava, R.; Buelow, C.; Bunting, P.; Duncan, C.; Fatoyinbo, L.; Friess, D.A.; Goldberg, L.; Hilarides, L.; et al. Harnessing Big Data to Support the Conservation and Rehabilitation of Mangrove Forests Globally. *One Earth* **2020**, *2*, 429–443. [CrossRef]
5. Spurgeon, J. The Socio-Economic Costs and Benefits of Coastal Habitat Rehabilitation and Creation. *Mar. Pollut. Bull.* **1999**, *37*, 373–382. [CrossRef]
6. Jerath, M.; Bhat, M.; Rivera-Monroy, V.H.; Castaneda-Moya, E.; Simard, M.; Twilley, R.R. The role of economic, policy, and ecological factors in estimating the value of carbon stocks in Everglades mangrove forests, South Florida, USA. *Environ. Sci. Policy* **2016**, *66*, 160–169. [CrossRef]
7. Bouillon, S.; Borges, A.V.; Castaneda-Moya, E.; Diele, K.; Dittmar, T.; Duke, N.C.; Kristensen, E.; Lee, S.Y.; Marchand, C.; Middelburg, J.J.; et al. Mangrove production and carbon sinks: A revision of global budget estimates. *Glob. Biogeochem. Cycles* **2008**, *22*, 1–12. [CrossRef]
8. Bunting, P.; Rosenqvist, A.; Lucas, R.M.; Rebelo, L.-M.; Hilarides, L.; Thomas, N.; Hardy, A.; Itoh, T.; Shimada, M.; Finlayson, C.M. The Global Mangrove Watch—A New 2010 Global Baseline of Mangrove Extent. *Remote Sens.* **2018**, *10*, 1669. [CrossRef]

9. Thomas, N.; Lucas, R.; Bunting, P.; Hardy, A.; Rosenqvist, A.; Simard, M. Distribution and drivers of global mangrove forest change, 1996–2010. *PLoS ONE* **2017**, *12*, e0179302. [CrossRef]
10. Thomas, N.; Bunting, P.; Lucas, R.; Hardy, A.; Rosenqvist, A.; Fatoyinbo, T. Mapping Mangrove Extent and Change: A Globally Applicable Approach. *Remote Sens.* **2018**, *10*, 1466. [CrossRef]
11. Giri, C.; Ochieng, E.; Tieszen, L.L.; Zhu, Z.; Singh, A.; Loveland, T.; Masek, J.; Duke, N. Status and distribution of mangrove forests of the world using earth observation satellite data. *Glob. Ecol. Biogeogr.* **2011**, *20*, 154–159. [CrossRef]
12. Friess, D.A.; Webb, E.L. Variability in mangrove change estimates and implications for the assessment of ecosystem service provision. *Glob. Ecol. Biogeogr.* **2014**, *23*, 715–725. [CrossRef]
13. Field, C.D. Rehabilitation of Mangrove Ecosystems: An Overview. *Mar. Pollut. Bull.* **1999**, *37*, 383–392. [CrossRef]
14. Lewis, R.R. Ecological engineering for successful management and restoration of mangrove forests. *Ecol. Eng.* **2005**, *24*, 403–418. [CrossRef]
15. López-Portillo, J.; Lewis, R.R.; Saenger, P.; Rovai, A.; Koedam, N.; Dahdouh-Guebas, F.; Agraz-Hernández, C.; Rivera-Monroy, V.H. *Mangrove Forest Restoration and Rehabilitation*; Springer International Publishing: Cham, Switzerland, 2017; pp. 301–345. [CrossRef]
16. Twilley, R.R.; Rivera-Monroy, V.H. Developing performance measures of mangrove wetlands using simulation models of hydrology, nutrient biogeochemistry, and community dynamics. *J. Coast. Res.* **2005**, *40*, 79–93.
17. Barbier, E.B. Natural barriers to natural disasters: Replanting mangroves after the tsunami. *Front. Ecol. Environ.* **2006**, *4*, 124–131. [CrossRef]
18. Ellison, A.M.; Felson, A.J.; Friess, D.A. Mangrove Rehabilitation and Restoration as Experimental Adaptive Management. *Front. Mar. Sci.* **2020**, *7*, 327. [CrossRef]
19. Twilley, R.R.; Rivera-Monroy, V.H.; Chen, R.H.; Botero, L. Adapting an ecological mangrove model to simulate trajectories in restoration ecology. *Mar. Pollut. Bull.* **1998**, *37*, 404–419. [CrossRef]
20. Andradi-Brown, D.A.; Howe, C.; Mace, G.M.; Knight, A.T. Do mangrove forest restoration or rehabilitation activities return biodiversity to pre-impact levels? *Environ. Evid.* **2013**, *2*, 20. [CrossRef]
21. Gijsman, R.; Horstman, E.M.; van der Wal, D.; Friess, D.A.; Swales, A.; Wijnberg, K.M. Nature-Based Engineering: A Review on Reducing Coastal Flood Risk With Mangroves. *Front. Mar. Sci.* **2021**, *8*, 825. [CrossRef]
22. Lugo, A.E. Mangrove forests: A tough system to invade but an easy one to rehabilitate. *Mar. Pollut. Bull.* **1998**, *37*, 427–430. [CrossRef]
23. Bosire, J.O.; Dahdouh-Guebas, F.; Walton, M.; Crona, B.I.; Lewis, R.R.; Field, C.; Kairo, J.G.; Koedam, N. Functionality of restored mangroves: A review. *Aquat. Bot.* **2008**, *89*, 251–259. [CrossRef]
24. Rastetter, E.B.; Ohman, M.D.; Elliott, K.J.; Rehage, J.S.; Rivera-Monroy, V.H.; Boucek, R.E.; Castañeda-Moya, E.; Danielson, T.M.; Gough, L.; Groffman, P.M.; et al. Time lags: Insights from the U.S. Long Term Ecological Research Network. *Ecosphere* **2021**, *12*, e03431. [CrossRef]
25. Danielson, T.M.; Rivera-Monroy, V.H.; Castaneda-Moya, E.; Briceno, H.; Travieso, R.; Marx, B.D.; Gaiser, E.; Farfan, L.M. Assessment of Everglades mangrove forest resilience: Implications for above-ground net primary productivity and carbon dynamics. *For. Ecol. Manag.* **2017**, *404*, 115–125. [CrossRef]
26. Mitsch, W.J.; Gosselink, J.G. *Wetlands*, 3rd ed.; John Wiley & Sons: New York, NY, USA, 2015; p. 736.
27. Rivera-Monroy, V.H.; Lee, S.Y.; Kristensen, E.; Twilley, R.R. *Mangrove Ecosystems: A Global Biogeographic Perspective*; Springer: New York, NY, USA, 2017; p. 397.
28. Kristensen, E.; Connolly, R.M.; Otero, X.L.; Marchand, M.; Ferreira, T.O.; Rivera-Monroy, V.H. Chapter 11. Biogeochemical cycles: Global approaches and perspectives. In *Mangrove Ecosystems: A Global Biogeographic Perspective Structure, Function and Ecosystem Services*; Rivera-Monroy, V.H., Lee, S.Y., Kristensen, E., Twilley, R.R., Eds.; Springer: New York, NY, USA, 2017; pp. 163–219.
29. Polidoro, B.A.; Carpenter, K.E.; Collins, L.; Duke, N.C.; Ellison, A.M.; Ellison, J.C.; Farnsworth, E.J.; Fernando, E.S.; Kathiresan, K.; Koedam, N.E.; et al. The Loss of Species: Mangrove Extinction Risk and Geographic Areas of Global Concern. *PLoS ONE* **2010**, *5*, e10095. [CrossRef]
30. Duke, N.C. Mangrove Floristics and Biogeography Revisited: Further Deductions from Biodiversity Hot Spots, Ancestral Discontinuities, and Common Evolutionary Processes. In *Mangrove Ecosystems: A Global Biogeographic Perspective: Structure, Function, and Services*; Rivera-Monroy, V.H., Lee, S.Y., Kristensen, E., Twilley, R.R., Eds.; Springer: Cham, Switzerland, 2017; pp. 17–53. [CrossRef]
31. Pérez-Ceballos, R.; Zaldívar-Jiménez, A.; Canales-Delgadillo, J.; López-Adame, H.; López-Portillo, J.; Merino-Ibarra, M. Determining hydrological flow paths to enhance restoration in impaired mangrove wetlands. *PLoS ONE* **2020**, *15*, e0227665. [CrossRef]
32. Twilley, R.R.; Rivera-Monroy, V.H.; Rovai, A.S.; Castañeda-Moya, E.; Davis, S. Chapter 21—Mangrove Biogeochemistry at Local to Global Scales Using Ecogeomorphic Approaches. In *Coastal Wetlands*; Perillo, G.M.E., Wolanski, E., Cahoon, D.R., Hopkinson, C.S., Eds.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 717–785. [CrossRef]
33. Medina-Calderón, J.H.; Mancera-Pineda, J.E.; Castañeda-Moya, E.; Rivera-Monroy, V.H. Hydroperiod and Salinity Interactions Control Mangrove Root Dynamics in a Karstic Oceanic Island in the Caribbean Sea (San Andres, Colombia). *Front. Mar. Sci.* **2021**, *7*, 1194. [CrossRef]

34. Lucas, R.; Lule, A.V.; Rodríguez, M.T.; Kamal, M.; Thomas, N.; Asbridge, E.; Kuenzer, C. *Spatial Ecology of Mangrove Forests: A Remote Sensing Perspective*; Springer International Publishing: Cham, Switzerland, 2017; pp. 87–112. [CrossRef]
35. Lugo, A.E.; Medina, E.; McGinley, K. Issues and challenges of Mangrove conservation in the Anthropocene. *Madera Y Bosques* **2014**, *20*, 11–38. [CrossRef]
36. Rivera-Monroy, V.H.; Twiley, R.R.; Mancera-Pineda, J.E.; Madden, C.J.; Alcantara-Eguren, A.; Moser, E.B.; Jonsson, B.R.; Castañeda-Moya, E.; Casas-Monroy, O.; Reyes-Forero, P.; et al. Salinity and Chlorophyll a as Performance Measures to Rehabilitate a Mangrove-Dominated Deltaic Coastal Region: The Ciénaga Grande de Santa Marta-Pajarales Lagoon Complex, Colombia. *Estuar. Coasts* **2011**, *34*, 1–19. [CrossRef]
37. Torres-Guevara, L.E.; Schlüter, A.; Claudia Lopez, C.M. Collective action in a tropical estuarine lagoon: Adapting Ostrom's SES framework to Ciénaga Grande de Santa Marta, Colombia. *Int. J. Commons* **2016**, *10*, 334–362. [CrossRef]
38. Jaramillo, F.; Brown, I.; Castellazzi, P.; Espinosa, L.; Guittard, A.; Hong, S.H.; Rivera-Monroy, V.H.; Wdowinski, S. Assessment of hydrologic connectivity in an ungauged wetland with InSAR observations. *Environ. Res. Lett.* **2018**, *13*, 024003. [CrossRef]
39. Valderrama-Landeros, L.H.; López-Portillo, J.; Velázquez-Salazar, S.; Alcántara-Maya, J.A.; Troche-Souza, C.; Rodríguez-Zúñiga, M.T.; Vázquez-Balderas, B.; Villeda-Chávez, E.; Cruz-López, M.I.; Ressl, R. Regional Distribution and Change Dynamics of Mangroves in México between 1970/80 and 2015. *Wetlands* **2020**, *40*, 1295–1305. [CrossRef]
40. Duke, N.C.; Kovacs, J.M.; Griffiths, A.D.; Preece, L.; Hill, D.J.E.; Van Oosterzee, P.; Mackenzie, J.; Morning, H.S.; Burrows, D. Large-scale dieback of mangroves in Australia. *Mar. Freshw. Res.* **2017**, *68*, 1816. [CrossRef]
41. Sklar, F.H.; Chimney, M.J.; Newman, S.; McCormick, P.; Gawlik, D.; Miao, S.L.; McVoy, C.; Said, W.; Newman, J.; Coronado, C.; et al. The ecological-societal underpinnings of Everglades restoration. *Front. Ecol. Environ.* **2005**, *3*, 161–169.
42. Rivera-Monroy, V.H.; Twilley, R.R.; Davis, S.E.; Childers, D.L.; Simard, M.; Chambers, R.; Jaffe, R.; Boyer, J.N.; Rudnick, D.T.; Zhang, K.; et al. The Role of the Everglades Mangrove Ecotone Region (EMER) in Regulating Nutrient Cycling and Wetland Productivity in South Florida. *Crit. Rev. Environ. Sci. Technol.* **2011**, *41*, 633–669. [CrossRef]
43. Simard, M.; Fatoyinbo, L.; Smetanka, C.; Rivera-Monroy, V.H.; Castaneda-Moya, E.; Thomas, N.; Van der Stocken, T. Mangrove canopy height globally related to precipitation, temperature and cyclone frequency. *Nat. Geosci.* **2019**, *12*, 40–45. [CrossRef]
44. Simard, M.; Rivera-Monroy, V.H.; Mancera-Pineda, J.E.; Castaneda-Moya, E.; Twilley, R.R. A systematic method for 3D mapping of mangrove forests based on Shuttle Radar Topography Mission elevation data, ICEsat/GLAS waveforms and field data: Application to Cienaga Grande de Santa Marta, Colombia. *Remote Sens. Environ.* **2008**, *112*, 2131–2144. [CrossRef]
45. Simard, M.; Zhang, K.; Rivera-Monroy, V.H.; Ross, M.S.; Ruiz, P.L.; Castañeda-Moya, E.; Twilley, R.R.; Rodriguez, E. Mapping height and biomass of mangrove forests in Everglades National Park with SRTM elevation data. *Photogramm. Eng. Remote Sens.* **2006**, *72*, 299–311. [CrossRef]
46. Berger, U.; Rivera-Monroy, V.H.; Doyle, T.W.; Dahdouh-Guebas, F.; Duke, N.C.; Fontalvo-Herazo, M.L.; Hildenbrandt, H.; Koedam, N.; Mehlig, U.; Piou, C. Advances and limitations of individual-based models to analyze and predict dynamics of mangrove forests: A review. *Aquat. Bot.* **2008**, *89*, 260–274. [CrossRef]
47. Zhao, X.C.; Rivera-Monroy, V.H.; Wang, H.Q.; Xue, Z.G.; Tsai, C.F.; Willson, C.S.; Castaneda-Moya, E.; Twilley, R.R. Modeling soil porewater salinity in mangrove forests (Everglades, Florida, USA) impacted by hydrological restoration and a warming climate. *Ecol. Model.* **2020**, *436*, 109292. [CrossRef]
48. FAO. *Global Forest Resources Assessment 2020: Main report*; FAO: Rome, Italy, 2020.
49. Xie, Y.; Sha, Z.; Yu, M. Remote sensing imagery in vegetation mapping: A review. *J. Plant Ecol.* **2008**, *1*, 9–23. [CrossRef]
50. Klemas, V. Remote sensing of emergent and submerged wetlands: An overview. *Int. J. Remote Sens.* **2013**, *34*, 6286–6320. [CrossRef]
51. Giri, C.; Zhu, Z.; Tieszen, L.L.; Singh, A.; Gillette, S.; Kelmelis, J.A. Mangrove forest distributions and dynamics (1975–2005) of the tsunami-affected region of Asia. *J. Biogeogr.* **2008**, *35*, 519–528. [CrossRef]
52. Wang, L.; Jia, M.; Yin, D.; Tian, J. A review of remote sensing for mangrove forests: 1956–2018. *Remote Sens. Environ.* **2019**, *231*, 111223. [CrossRef]
53. Tang, W.; Zheng, M.; Zhao, X.; Shi, J.; Yang, J.; Trettin, C. Big Geospatial Data Analytics for Global Mangrove Biomass and Carbon Estimation. *Sustainability* **2018**, *10*, 472. [CrossRef]
54. Lucas, R.; Van De Kerchove, R.; Otero, V.; Lagomasino, D.; Fatoyinbo, L.; Omar, H.; Satyanarayana, B.; Dahdouh-Guebas, F. Structural characterisation of mangrove forests achieved through combining multiple sources of remote sensing data. *Remote Sens. Environ.* **2020**, *237*, 111543. [CrossRef]
55. Kennedy, R.E.; Andrefouet, S.; Cohen, W.B.; Gomez, C.; Griffiths, P.; Hais, M.; Healey, S.P.; Helmer, E.H.; Hostert, P.; Lyons, M.B.; et al. Bringing an ecological view of change to Landsat-based remote sensing. *Front. Ecol. Environ.* **2014**, *12*, 339–346. [CrossRef]
56. Djenontin, I.N.S.; Meadow, A.M. The art of co-production of knowledge in environmental sciences and management: Lessons from international practice. *Environ. Manag.* **2018**, *61*, 885–903. [CrossRef]
57. Wu, W.-T.; Zhou, Y.-X.; Tian, B. Coastal wetlands facing climate change and anthropogenic activities: A remote sensing analysis and modelling application. *Ocean. Coast. Manag.* **2017**, *138*, 1–10. [CrossRef]
58. Klemas, V. Remote sensing of wetlands: Case studies comparing practical techniques. *J. Coast. Res.* **2011**, *27*, 418–427. [CrossRef]
59. Moffett, K.; Nardin, W.; Silvestri, S.; Wang, C.; Temmerman, S. Multiple Stable States and Catastrophic Shifts in Coastal Wetlands: Progress, Challenges, and Opportunities in Validating Theory Using Remote Sensing and Other Methods. *Remote Sens.* **2015**, *7*, 10184–10226. [CrossRef]

60. Wu, W.; Yang, Z.; Chen, C.; Tian, B. Tracking the environmental impacts of ecological engineering on coastal wetlands with numerical modeling and remote sensing. *J. Environ. Manag.* **2022**, *302*, 113957. [CrossRef] [PubMed]
61. Ozesmi, S.L.; Bauer, M.E. Satellite remote sensing of wetlands. *Wetl. Ecol. Manag.* **2002**, *10*, 381–402. [CrossRef]
62. Wang, H.Q.; Steyer, G.D.; Couvillion, B.R.; Beck, H.J.; Rybczyk, J.M.; Rivera-Monroy, V.H.; Krauss, K.W.; Visser, J.M. Predicting landscape effects of Mississippi River diversions on soil organic carbon sequestration. *Ecosphere* **2017**, *8*, e01984. [CrossRef]
63. Velázquez-Salazar, S.; Rodríguez-Zúñiga, M.T.; Alcántara-Maya, J.A.; Villeda-Chávez, E.; Valderrama-Landeros, L.; Troche-Souza, C.; Vázquez-Balderas, B.; Pérez-Espinosa, I.; Cruz-López, M.I.; Ressl, R.; et al. *Manglares de México. Actualización y Análisis de los datos 2020*; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad México City: México City, Mexico, 2021; p. 168.
64. CONABIO. *Sitios de Manglar Con Relevancia Biológica Y Con Necesidades de Rehabilitación Ecológica (Escala: 1:50000)*; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad: Sistema de Monitoreo de los Manglares de México (SMMM): Mexico City, Mexico, 2009; p. 50.
65. Rodríguez-Zúñiga, M.T.; Troche-Souza, C.; Vázquez-Lule, A.D.; Márquez-Mendoza, J.D.; Vázquez-Balderas, B.; Valderrama-Landeros, L.; Velázquez-Salazar, S.; Cruz-López, M.I.; Ressl, R.; Uribe-Martínez, A.; et al. *Manglares de México/Extensión, Distribución y Monitoreo*; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad: Mexico City, Mexico, 2013; p. 128.
66. Valderrama-Landeros, L.H.; Rodríguez-Zúñiga, M.T.; Troche-Souza, C.; Velázquez-Salazar, S.; Villeda-Chávez, E.; Alcántara-Maya, J.A.; Vázquez-Balderas, B.; Cruz-López, M.I.; Ressl, R. *Manglares de México: Actualización y Exploración de los datos del Sistema de Monitoreo 1970/1980–2015*; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad: Mexico City, Mexico, 2017; p. 128.
67. Eisenhauer, E.; Williams, K.C.; Margeson, K.; Paczuski, S.; Hano, M.C.; Mulvaney, K. Advancing translational research in environmental science: The role and impact of social sciences. *Environ. Sci. Policy* **2021**, *120*, 165–172. [CrossRef]
68. Schlesinger, W.H. Translational Ecology. *Science* **2010**, *329*, 609. [CrossRef]
69. Kirchhoff, C.J.; Carmen Lemos, M.; Dessai, S. Actionable Knowledge for Environmental Decision Making: Broadening the Usability of Climate Science. *Annu. Rev. Environ. Resour.* **2013**, *38*, 393–414. [CrossRef]
70. Cavanaugh, K.C.; Kellner, J.R.; Forde, A.J.; Gruner, D.S.; Parker, J.D.; Rodriguez, W.; Feller, I.C. Poleward expansion of mangroves is a threshold response to decreased frequency of extreme cold events. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 723–727. [CrossRef]
71. Rivera-Monroy, V.H.; Osland, M.J.; Day, J.W.; Ray, S.; Rovai, A.S.; Day, R.H.; Mukherjee, J. Advancing Mangrove Macroecology. In *Mangrove Ecosystems: A Global Biogeographic Perspective: Structure, Function and Ecosystem Services*; Rivera-Monroy, V.H., Kristensen, E., Lee, S.Y., Twilley, R.R., Eds.; Springer: New York, NY, USA, 2017; pp. 347–371.
72. Godoy, M.D.P.; Lacerda, L.D.D. Mangroves Response to Climate Change: A Review of Recent Findings on Mangrove Extension and Distribution. *Acad Bras Cienc* **2015**, *87*, 651–667. [CrossRef]
73. Watson, E.; Hinojosa Corona, A. Assessment of Blue Carbon Storage by Baja California (Mexico) Tidal Wetlands and Evidence for Wetland Stability in the Face of Anthropogenic and Climatic Impacts. *Sensors* **2017**, *18*, 32. [CrossRef]
74. Rodríguez, F.V.L. *Mangrove Concessions: An Innovative Strategy for Community Mangrove Conservation in Ecuador*; Springer: Cham, Switzerland, 2018; pp. 557–578. [CrossRef]
75. Rodríguez-Rodríguez, J.A.; Mancera-Pineda, J.E.; Tavera, H. Mangrove restoration in Colombia: Trends and lessons learned. *For. Ecol. Manag.* **2021**, *496*, 119414. [CrossRef]
76. Lizano, O.G.; Amador, J.; Soto, R. Mangrove characterization of Central America with remote sensors. *Rev. Biol. Trop.* **2001**, *49* (Suppl. S2), 331–340. [PubMed]
77. Ferreira, A.C.; Lacerda, L.D. Degradation and conservation of Brazilian mangroves, status and perspectives. *Ocean. Coast. Manag.* **2016**, *125*, 38–46. [CrossRef]
78. Sales, E.; Rodas, O.; Valenzuela, O.; Hillbrand, A.; Sabogal, C. On the way to restore Guatemala's degraded lands: Creating governance conditions. *World Dev. Perspect.* **2016**, *4*, 16–18. [CrossRef]
79. Sherman, R.E.; Timothy, F.; Martinez, P. Spatial Patterns of Biomass and Aboveground Net Primary Productivity in a Mangrove Ecosystem in the Dominican Republic. *Ecosystems* **2003**, *6*, 384–398. [CrossRef]
80. Lacerda, L.D.; Borges, R.; Ferreira, A.C. Neotropical mangroves: Conservation and sustainable use in a scenario of global climate change. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2019**, *29*, 1347–1364. [CrossRef]
81. Simenstad, C.A.; Reed, D.J.; Ford, M.A. When is restoration not?: Incorporating landscape-scale processes to restore self-sustaining ecosystems in coastal wetland restoration. *Ecol. Eng.* **2006**, *26*, 27–39. [CrossRef]
82. Calderon-Aguilera, L.E.; Rivera-Monroy, V.H.; Porter-Bolland, L.; Martínez-Yrízar, A.; Ladah, L.B.; Martínez-Ramos, M.; Alcocer, J.; Santiago-Pérez, A.L.; Hernandez-Arana, H.A.; Reyes-Gómez, V.M. An assessment of natural and human disturbance effects on Mexican ecosystems: Current trends and research gaps. *Biodivers. Conserv.* **2012**, *21*, 589–617. [CrossRef]
83. Fuller, T.; Sánchez-Cordero, V.; Illoldi-Rangel, P.; Linaje, M.; Sarkar, S. The cost of postponing biodiversity conservation in Mexico. *Biol. Conserv.* **2007**, *134*, 593–600. [CrossRef]
84. Omernik, J.M.; Griffith, G.E. Ecoregions of the Conterminous United States: Evolution of a Hierarchical Spatial Framework. *Environ. Manag.* **2014**, *54*, 1249–1266. [CrossRef]
85. Pontifes, P.A.; García-Meneses, P.M.; Gómez-Aíza, L.; Monterroso-Rivas, A.I.; Caso Chávez, M. Land use/land cover change and extreme climatic events in the arid and semi-arid ecoregions of Mexico. *Atmósfera* **2018**, *31*, 355–372. [CrossRef]
86. Cuervo-Robayo, A.P.; Ureta, C.; Gómez-Albores, M.A.; Meneses-Mosquera, A.K.; Téllez-Valdés, O.; Martínez-Meyer, E. One hundred years of climate change in Mexico. *PLoS ONE* **2020**, *15*, e0209808. [CrossRef] [PubMed]

87. Salinas-Rodríguez, S.; Barba-Macías, E.; Infante Mata, D.; Nava-López, M.; Neri-Flores, I.; Domínguez Varela, R.; González Mora, I. What Do Environmental Flows Mean for Long-term Freshwater Ecosystems' Protection? Assessment of the Mexican Water Reserves for the Environment Program. *Sustainability* **2021**, *13*, 1240. [CrossRef]
88. Gochis, D.J.; Brito-Castillo, L.; Shuttleworth, W.J. Hydroclimatology of the North American Monsoon region in northwest Mexico. *J. Hydrol.* **2006**, *316*, 53–70. [CrossRef]
89. González-Ramírez, J.; Parés-Sierra, A. Streamflow modeling of five major rivers that flow into the Gulf of Mexico using SWAT. *Atmósfera* **2019**, *32*, 261–272. [CrossRef]
90. Rivera-Monroy, V.H.; Farfan, L.M.; Brito-Castillo, L.; Cortes-Ramos, J.; Gonzalez-Rodriguez, E.; D'Sa, E.J.; Euan-Avila, J.I. Tropical Cyclone Landfall Frequency and Large-Scale Environmental Impacts along Karstic Coastal Regions (Yucatan Peninsula, Mexico). *Appl. Sci.-Basel* **2020**, *10*, 5815. [CrossRef]
91. Camacho-Ibar, V.F.; Rivera-Monroy, V.H. Coastal Lagoons and Estuaries in Mexico: Processes and Vulnerability. *Estuaries Coasts* **2014**, *37*, 1313–1318. [CrossRef]
92. Farfan, L.M.; D'Sa, E.J.; Liu, K.-B.; Rivera-Monroy, V.H. Tropical Cyclone Impacts on Coastal Regions: The Case of the Yucatan and the Baja California Peninsulas, Mexico. *Estuaries Coasts* **2014**, *37*, 1388–1402. [CrossRef]
93. Castañeda-Moya, E.; Rivera-Monroy, V.H.; Chambers, R.M.; Zhao, X.C.; Lamb-Wotton, L.; Gorsky, A.; Gaiser, E.E.; Troxler, T.G.; Kominoski, J.S.; Hiatt, M. Hurricanes fertilize mangrove forests in the Gulf of Mexico (Florida Everglades, USA). *Proc. Natl. Acad. Sci. USA* **2020**, *117*, 4831–4841. [CrossRef]
94. Zhao, X.; Rivera-Monroy, V.H.; Farfán, L.M.; Briceño, H.; Castañeda-Moya, E.; Travieso, R.; Gaiser, E.E. Tropical cyclones cumulatively control regional carbon fluxes in Everglades mangrove wetlands (Florida, USA). *Sci. Rep.* **2021**, *11*, 13927. [CrossRef]
95. CONABIO. *Distribución de los manglares en México en 2020, escala: 1:50000*; CONABIO: Ciudad de México, México, 2020.
96. INEGI. *Localidades de la República Mexicana 2020*; INEGI: Aguascalientes, México, 2020.
97. CONABIO. *'Curvas de nivel para la República Mexicana'. Escala 1:250,000. Extraído del Modelo Digital del Terreno*; CONABIO: Ciudad de México, México, 1998.
98. García, E. *'Climas' (clasificación de Köppen, modificado por García). Escala 1:1,000,000*; CONABIO: Ciudad de México, México, 1998.
99. INEGI, CONABIO, INE. Ecorregiones Terrestres de México. Escala 1:1000000; INEGI, CONABIO, INE: Ciudad de México, México, 2007.
100. Rodríguez-Zúñiga, M.T.; Troche-Souza, C.; Vázquez-Lule, A.D.; Márquez-Mendoza, J.D.; Vázquez- Balderas, B.; Valderrama-Landeros, L.; Velázquez-Salazar, S.; Uribe-Martínez, A.; Acosta-Velázquez, J.; Díaz-Gallegos, J.; et al. *Los Manglares de México: Estado Actual Y Establecimiento de un Programa de Monitoreo A Largo Plazo: 2ª y 3era Etapas. Informe Final SNIB-CONABIO Proyecto No. GQ004*; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad: Mexico City, Mexico, 2012.
101. CONANP. *Areas Naturales Protegidas Federales de México*; CONANP: Morelia, México, 2008.
102. CONANP. *Sitios Ramsar en México*; CONANP: Michoacán, México, 2008.
103. CONABIO. *Modelo Digital del Terreno de México. Extraido de los datos del CEM-INEGI, Escala 1:50,000*; CONABIO: Ciudad de México, México, 2005.
104. INEGI. *Datos Vectoriales de la Carta de Uso de Suelo y Vegetación, Serie I, Escala 1:250,000*; INE, INEGI: Mexico City, Mexico, 1999.
105. Valderrama, L.; Troche, C.; Rodriguez, M.T.; Marquez, D.; Vázquez, B.; Velázquez, S.; Vázquez, A.; Cruz, M.I.; Ressl, R. Evaluation of Mangrove Cover Changes in Mexico During the 1970–2005 Period. *Wetlands* **2014**, *34*, 747–758. [CrossRef]
106. Osland, M.J.; Feher, L.C.; Lopez-Portillo, J.; Day, R.H.; Suman, D.O.; Menendez, J.M.G.; Rivera-Monroy, V.H. Mangrove forests in a rapidly changing world: Global change impacts and conservation opportunities along the Gulf of Mexico coast. *Estuar. Coast. Shelf Sci.* **2018**, *214*, 120–140. [CrossRef]
107. Hernandez, C.T.; de la Lanza Espino, G. Ecologia, Produccion y Aprovechamiento del Mangle Conocarpus erectus L., en Barra de Tecoanapa Guerrero, Mexico. *Biotropica* **1999**, *31*, 121. [CrossRef]
108. Santamaría-Damián, S.; Romero-Berny, E.I.; Tovilla-Hernández, C.; Gallegos-Martínez, M.E. Recent records of Avicennia bicolor (Acanthaceae) on the Mexican Pacific coast with notes on its distribution and conservation status. *Hidrobiológica* **2019**, *29*, 197–202. [CrossRef]
109. Nettel, A.; Dodd, R.S.; Cid-Becerra, J.A.; De La Rosa-Velez, J. Ten new microsatellite markers for the buttonwood mangrove (Conocarpus erectus L., Combretaceae). *Mol. Ecol. Resour.* **2008**, *8*, 851–853. [CrossRef] [PubMed]
110. Gray, V.R. Rhizophora harrisonii. (Rhizophoraceae), un nuevo registro para las costas de Mexico. *B Soc. Bot. Mex.* **1981**, *41*, 163–165. [CrossRef]
111. Yarrow, M.M.; Salthe, S.N. Ecological boundaries in the context of hierarchy theory. *Biosystems* **2008**, *92*, 233–244. [CrossRef]
112. Wu, J. From balance of nature to hierarchical patch dynamics: A paradigma shift in ecology. *Q. Rev. Biol.* **1995**, *70*, 439–466. [CrossRef]
113. Wu, J. *Hierarchy Theory: An Overview*; Springer: Dordrecht, The Netherlands, 2013; pp. 281–301. [CrossRef]
114. Lugo, A.; Snedaker, S.C. The Ecology of Mangroves. *Annu. Rev. Ecol. Syst.* **1974**, *5*, 39–64. [CrossRef]
115. Twilley, R.R.; Rivera-Monroy, V.H. *Ecogeomorphic Models of Nutrient Biogeochemistry for Mangrove Wetlands In Coastal Wetlands: An Integrated Ecosystem Approach*; Perillo, G.M., Wolanski, E., Cahoon, D.R., Brinson, M.M., Eds.; Elsevier: Amsterdam, The Netherlands, 2009; pp. 641–683.
116. Sharma, R.; Hara, K. Characterization of Vegetation Physiognomic Types Using Bidirectional Reflectance Data. *Geosciences* **2018**, *8*, 394. [CrossRef]

117. Mishra, N.B.; Crews, K.A. Mapping vegetation morphology types in a dry savanna ecosystem: Integrating hierarchical object-based image analysis with Random Forest. *Int. J. Remote Sens.* **2014**, *35*, 1175–1198. [CrossRef]
118. Muchoney, D.; Strahler, A. Regional vegetation mapping and direct land surface parameterization from remotely sensed and site data. *Int. J. Remote Sens.* **2002**, *23*, 1125–1142. [CrossRef]
119. eoPortal Directory. SPOT-5. Available online: https://earth.esa.int/web/eoportal/satellite-missions/s/spot-5 (accessed on 5 February 2022).
120. Wikipedia. Sentinel-2. Available online: https://en.wikipedia.org/wiki/Sentinel-2 (accessed on 5 February 2022).
121. GIS Lounge. Landsat 8. Available online: https://www.gislounge.com/landsat-8/ (accessed on 5 February 2022).
122. Geoimag. Available online: https://www.geoimage.com.au/satellites-sensors/worldview-2/ (accessed on 5 February 2022).
123. López-Portillo, J.; Ezcurra, E.; Mass, J.M. Los petenes de Sian Ka'an, Quintana Roo y su relación con gradientes de presión hídrica. *Acta Bot. Mex.* **1989**, *5*, 19–29. [CrossRef]
124. Carr, J.; D'Odorico, P.; Engel, V.; Redwine, J. Tree island pattern formation in the Florida Everglades. *Ecol. Complex.* **2016**, *26*, 37–44. [CrossRef]
125. Duran-Garcia, R. Diversidad floristica de los Petenes de Campeche. *Acta Bot. Mex.* **1995**, *31*, 73–84. [CrossRef]
126. Lugo, A.E. The inland mangroves of Inagua. *J. Nat. Hist.* **1981**, *15*, 845–852. [CrossRef]
127. Woodroffe, C.D. *Coasts: Form, Process and Evolution*, 1st ed.; Cambridge University Press: Cambridge, UK, 2002.
128. Fatoyinbo, T.; Feliciano, E.A.; Lagomasino, D.; Lee, S.K.; Trettin, C. Estimating mangrove aboveground biomass from airborne LiDAR data: A case study from the Zambezi River delta. *Environ. Res. Lett.* **2018**, *13*, 025012. [CrossRef]
129. Fatoyinbo, T.E.; Simard, M. Height and biomass of mangroves in Africa from ICESat/GLAS and SRTM. *Int. J. Remote Sens.* **2013**, *34*, 668–681. [CrossRef]
130. Lagomasino, D.; Fatoyinbo, T.; Lee, S.; Feliciano, E.; Trettin, C.; Simard, M. A Comparison of Mangrove Canopy Height Using Multiple Independent Measurements from Land, Air, and Space. *Remote Sens.* **2016**, *8*, 372. [CrossRef]
131. Quoc Vo, T.; Kuenzer, C.; Oppelt, N. How remote sensing supports mangrove ecosystem service valuation: A case study in Ca Mau province, Vietnam. *Ecosyst. Serv.* **2015**, *14*, 67–75. [CrossRef]
132. Pham, T.D.; Xia, J.; Ha, N.T.; Bui, D.T.; Le, N.N.; Tekeuchi, W. A Review of Remote Sensing Approaches for Monitoring Blue Carbon Ecosystems: Mangroves, Seagrassesand Salt Marshes during 2010–2018. *Sensors* **2019**, *19*, 1933. [CrossRef] [PubMed]
133. Lanaras, C.; Bioucas-Dias, J.; Galliani, S.; Baltsavias, E.; Schindler, K. Super-resolution of Sentinel-2 images: Learning a globally applicable deep neural network. *Isprs. J. Photogramm.* **2018**, *146*, 305–319. [CrossRef]
134. Jia, M.; Wang, Z.; Wang, C.; Mao, D.; Zhang, Y. A New Vegetation Index to Detect Periodically Submerged Mangrove Forest Using Single-Tide Sentinel-2 Imagery. *Remote Sens.* **2019**, *11*, 2043. [CrossRef]
135. Purwanto, A.D.; Asriningrum, W. Identification of magnrove forests using multispectral satellite imageries. *Int. J. Remote Sens. Earth Sci.* **2019**, *16*, 63. [CrossRef]
136. Hu, L.; Xu, N.; Liang, J.; Li, Z.; Chen, L.; Zhao, F. Advancing the Mapping of Mangrove Forests at National-Scale Using Sentinel-1 and Sentinel-2 Time-Series Data with Google Earth Engine: A Case Study in China. *Remote Sens.* **2020**, *12*, 3120. [CrossRef]
137. Zhao, C.P.; Qin, C.Z. A detailed mangrove map of China for 2019 derived from Sentinel-1 and -2 images and Google Earth images. *Geosci. Data J.* **2021**. [CrossRef]
138. Manna, S.; Raychaudhuri, B. Mapping distribution of Sundarban mangroves using Sentinel-2 data and new spectral metric for detecting their health condition. *Geocarto Int.* **2020**, *35*, 434–452. [CrossRef]
139. FAO. *Forest Resources Assessment 1990: Survey of Tropical Forest Cover and Study of Change Processes*; Food and Agriculture Organization of the United Nations: Rome, Italy, 1996.
140. Leyca-Geosystems. *ERDAS Imagine Tour Guides-GIS & Mapping*; Leyca Geosystems Geospatial Imaging, LLC: Atlanta, GA, USA, 2003; p. 730.
141. Brodu, N. Super-Resolving Multiresolution Images With Band-Independent Geometry of Multispectral Pixels. *IEEE Trans. Geosci. Remote Sens.* **2017**, *55*, 4610–4617. [CrossRef]
142. Congalton, R.G.; Green, K. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*, 2nd ed.; CRC Press: Boca Raton, FL, USA, 2008. [CrossRef]
143. Ruiz-Luna, A.; Escobar, A.C.; Berlanga-Robles, C. Assessing Distribution Patterns, Extent, and Current Condition of Northwest Mexico Mangroves. *Wetlands* **2010**, *30*, 717–723. [CrossRef]
144. Ruiz-Ramirez, J.D.; Euan-Avila, J.I.; Rivera-Monroy, V.H. Vulnerability of Coastal Resort Cities to Mean Sea Level Rise in the Mexican Caribbean. *Coast. Manag.* **2019**, *47*, 23–43. [CrossRef]
145. Lee, S.Y.; Primavera, J.H.; Dahdouh-Guebas, F.; McKee, K.; Bosire, J.O.; Cannicci, S.; Diele, K.; Fromard, F.; Koedam, N.; Marchand, C.; et al. Ecological role and services of tropical mangrove ecosystems: A reassessment. *Glob. Ecol. Biogeogr.* **2014**, *23*, 726–743. [CrossRef]
146. Manez, K.S.; Krause, G.; Ring, I.; Glaser, M. The Gordian knot of mangrove conservation: Disentangling the role of scale, services and benefits. *Glob. Environ. Change-Hum. Policy Dimens.* **2014**, *28*, 120–128. [CrossRef]
147. Sarukhán, J.; Urquiza-Haas, T.; Koleff, P.; Carabias, J.; Dirzo, R.; Ezcurra, E.; Cerdeira-Estrada, S.; Soberón, J. Strategic Actions to Value, Conserve, and Restore the Natural Capital of Megadiversity Countries: The Case of Mexico. *BioScience* **2015**, *65*, 164–173. [CrossRef] [PubMed]

148. Sarukhán, J.; Jiménez, R. Generating intelligence for decision making and sustainable use of natural capital in Mexico. *Curr. Opin. Environ. Sustain.* **2016**, *19*, 153–159. [CrossRef]
149. Soberon, J.M.; Sarukhan, J.K. A new mechanism for science-policy transfer and biodiversity governance? *Environ. Conserv.* **2009**, *36*, 265–267. [CrossRef]
150. CONABIO. Biodiversidad Mexicana. Available online: https://www.biodiversidad.gob.mx/ (accessed on 20 December 2021).
151. Sarukhán, J.; Koleff, P.; Carabias, J.; Soberon, J.; Dirzo, R.; Llorente-Bousquets, J.; Halfter, G.; Gonzales, R.; March, I.; Mohar, A.; et al. *Capital Natural de México-Síntesis: Conocimiento Actual, Evaluación y Perspectivas de Sustentabilidad*; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad: Mexico City, Mexico, 2009; p. 100.
152. Rodríguez-Zúñiga, M.T.; Villeda-Chávez, E.; Vázquez-Lule, A.D.; Bejarano, M.; Cruz-López, M.I.; Olguín, M.; Villela Gaytán, S.A.; Flores, R. *Métodos Para la Caracterización de los Manglares Mexicanos: Un Enfoque Espacial Multiescala*; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad: Ciudad de México, México, 2018; p. 272.
153. Velázquez-Salazar, S.; Valderrama-Landeros, L.H.; Rodríguez-Zúñiga, M.T.; Cruz-López, M.I. Anthropization in the coastal zone associated with Mexican mangroves (2005–2015). *Environ. Monit. Assess.* **2019**, *191*, 521. [CrossRef]
154. Rivera-Arriaga, E.; Villalobos, G. The coast of Mexico: Approaches for its management. *Ocean. Coast. Manag.* **2001**, *44*, 729–756. [CrossRef]
155. Castañeda-Moya, E.; Twilley, R.R.; Rivera-Monroy, V.H. Allocation of biomass and net primary productivity of mangrove forests along environmental gradients in the Florida Coastal Everglades, USA. *For. Ecol. Manag.* **2013**, *307*, 226–241. [CrossRef]
156. Lara-Domínguez, A.L.; Day, J.W.; Zapata, G.V.; Twilley, R.R.; Guillén, H.A.; Yáñez-Arancibia, A. Structure of a unique inland mangrove forest assemblage in fossil lagoons on the Caribbean Coast of Mexico. *Wetl. Ecol. Manag.* **2005**, *13*, 111–122. [CrossRef]
157. Castañeda-Moya, E.; Rivera-Monroy, V.H.; Twilley, R.R. Mangrove zonation in the dry life zone of the Gulf of Fonseca, Honduras. *Estuaries Coasts* **2006**, *29*, 751–764. [CrossRef]
158. Ochoa-Gomez, J.G.; Lluch-Cota, S.E.; Rivera-Monroy, V.H.; Lluch-Cota, D.B.; Troyo-Dieguez, E.; Oechel, W.; Serviere-Zaragoza, E. Mangrove wetland productivity and carbon stocks in an arid zone of the Gulf of California (La Paz Bay, Mexico). *For. Ecol. Manag.* **2019**, *442*, 135–147. [CrossRef]
159. Clinton, N.; Stuhlmacher, M.; Miles, A.; Uludere Aragon, N.; Wagner, M.; Georgescu, M.; Herwig, C.; Gong, P. A Global Geospatial Ecosystem Services Estimate of Urban Agriculture. *Earth's Future* **2018**, *6*, 40–60. [CrossRef]
160. Fawcett, D.; Bennie, J.; Anderson, K. Monitoring spring phenology of individual tree crowns using drone-acquired NDVI data. *Remote Sens. Ecol. Conserv.* **2021**, *7*, 227–244. [CrossRef]
161. Fawcett, D.; Panigada, C.; Tagliabue, G.; Boschetti, M.; Celesti, M.; Evdokimov, A.; Biriukova, K.; Colombo, R.; Miglietta, F.; Rascher, U.; et al. Multi-Scale Evaluation of Drone-Based Multispectral Surface Reflectance and Vegetation Indices in Operational Conditions. *Remote Sens.* **2020**, *12*, 514. [CrossRef]
162. Gorelick, N.; Hancher, M.; Dixon, M.; Ilyushchenko, S.; Thau, D.; Moore, R. Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sens. Environ.* **2017**, *202*, 18–27. [CrossRef]
163. Shumway, R.H.; Stoffer, D. *Time Series Analysis and Its Applications: With R Examples*; Springer: New York, NY, USA, 2017.
164. Yancho, J.; Jones, T.; Gandhi, S.; Ferster, C.; Lin, A.; Glass, L. The Google Earth Engine Mangrove Mapping Methodology (GEEMMM). *Remote Sens.* **2020**, *12*, 3758. [CrossRef]
165. Quintero-Morales, M.A.; Plata-Rocha, W.; Monjardín-Armenta, S.A.; Olimón-Andalón, V.; Torres-Montoya, E.H. Geospatial Simulation Model of Sustainable Mangrove Development Scenarios for the Years 2030 and 2050 in Marismas Nacionales, Mexico. *Sustainability* **2021**, *13*, 9551. [CrossRef]
166. Flores-Verdugo, F.; Amezcua, F.; Kovacs, J.M.; Serrano, D.; Blanco-Correa, M. *Changes in the Hydrological Regime of Coastal Lagoons Affect Mangroves and Small Scale Fisheries: The Case of the Mangrove-Estuarine Complex of Marismas Nacionales (Pacific Coast of Mexico)*; Springer: Dordrecht, The Netherlands, 2014; pp. 81–91. [CrossRef]
167. Adame, M.F.; Zaldívar-Jimenez, A.; Teutli, C.; Caamal, J.P.; Andueza, M.T.; López-Adame, H.; Cano, R.; Hernández-Arana, H.A.; Torres-Lara, R.; Herrera-Silveira, J.A. Drivers of Mangrove Litterfall within a Karstic Region Affected by Frequent Hurricanes. *Biotropica* **2013**, *45*, 147–154. [CrossRef]
168. Emanuel, K. Atlantic tropical cyclones downscaled from climate reanalyses show increasing activity over past 150 years. *Nat. Commun.* **2021**, *12*, 7027. [CrossRef]
169. Goni, G.; Demaria, M.; Knaff, J.; Sampson, C.; Ginis, I.; Bringas, F.; Mavume, A.; Lauer, C.; Lin, I.I.; Ali, M.M.; et al. Applications of Satellite-Derived Ocean Measurements to Tropical Cyclone Intensity Forecasting. *Oceanography* **2009**, *22*, 190–197. [CrossRef]
170. Svejkovsky, J.; Ogurcak, D.E.; Ross, M.S.; Arkowitz, A. Satellite Image-Based Time Series Observations of Vegetation Response to Hurricane Irma in the Lower Florida Keys. *Estuaries Coasts* **2020**, *43*, 1058–1069. [CrossRef]
171. Pastor-Guzman, J.; Dash, J.; Atkinson, P.M. Remote sensing of mangrove forest phenology and its environmental drivers. *Remote Sens. Environ.* **2018**, *205*, 71–84. [CrossRef]
172. Valderrama-Landeros, L.; Flores-De-Santiago, F.; Kovacs, J.M.; Flores-Verdugo, F. An assessment of commonly employed satellite-based remote sensors for mapping mangrove species in Mexico using an NDVI-based classification scheme. *Environ. Monit. Assess.* **2018**, *190*, 1–13. [CrossRef] [PubMed]
173. Valderrama-Landeros, L.; Blanco Y Correa, M.; Flores-Verdugo, F.; Álvarez-Sánchez, L.F.; Flores-De-Santiago, F. Spatiotemporal shoreline dynamics of Marismas Nacionales, Pacific coast of Mexico, based on a remote sensing and GIS mapping approach. *Environ. Monit. Assess.* **2020**, *192*, 23. [CrossRef]

174. Valderrama-Landeros, L.H.; Martell-Dubois, R.; Ressl, R.; Silva-Casarín, R.; Cruz-Ramírez, C.J.; Muñoz-Pérez, J.J. Dynamics of coastline changes in Mexico. *J. Geogr. Sci.* **2019**, *29*, 1637–1654. [CrossRef]
175. Krauss, K.W.; McKee, K.L.; Lovelock, C.E.; Cahoon, D.R.; Saintilan, N.; Reef, R.; Chen, L. How mangrove forests adjust to rising sea level. *New Phytol.* **2014**, *202*, 19–34. [CrossRef]
176. Saintilan, N.; Khan, N.S.; Ashe, E.; Kelleway, J.J.; Rogers, K.; Woodroffe, C.D.; Horton, B.P. Thresholds of mangrove survival under rapid sea level rise. *Science* **2020**, *368*, 1118–1121. [CrossRef]
177. Woodroffe, C.D.; Rogers, K.; McKee, K.L.; Lovelock, C.E.; Mendelssohn, I.A.; Saintilan, N. Mangrove Sedimentation and Response to Relative Sea-Level Rise. *Annu. Rev. Mar. Sci.* **2016**, *8*, 243–266. [CrossRef]
178. Thinh, N.A.; Hens, L. A Digital Shoreline Analysis System (DSAS) applied on mangrove shoreline changes along the Giao Thuy coastal area (Nam Dinh, Vietnam) during 2005-2014. *Vietnam. J. Earth Sci.* **2017**, *39*, 87–96. [CrossRef]
179. Thieler, E.R.; Himmelstoss, E.A.; Zichichi, J.L.; Ergul, A. *Digital Shoreline Analysis System (DSAS) Version 4.0—An ArcGIS Extension for Calculating Shoreline Change*; U.S. Geological Survey: Reston, VA, USA, 2009.
180. Haddad, N.M.; Brudvig, L.A.; Clobert, J.; Davies, K.F.; Gonzalez, A.; Holt, R.D.; Lovejoy, T.E.; Sexton, J.O.; Austin, M.P.; Collins, C.D.; et al. Habitat fragmentation and its lasting impact on Earth's ecosystems. *Sci. Adv.* **2015**, *1*, e1500052. [CrossRef]
181. Uroy, L.; Ernoult, A.; Mony, C. Effect of landscape connectivity on plant communities: A review of response patterns. *Landsc. Ecol.* **2019**, *34*, 203–225. [CrossRef]
182. Stoate, C.; Boatman, N.D.; Borralho, R.J.; Carvalho, C.R.; de Snoo, G.R.; Eden, P. Ecological impacts of arable intensification in Europe. *J. Environ. Manag.* **2001**, *63*, 337–365. [CrossRef] [PubMed]
183. Rovai, A.S.; Riul, P.; Twilley, R.R.; Castaneda-Moya, E.; Rivera-Monroy, V.H.; Williams, A.A.; Simard, M.; Cifuentes-Jara, M.; Lewis, R.R.; Crooks, S.; et al. Scaling mangrove aboveground biomass from site-level to continental-scale. *Glob. Ecol. Biogeogr.* **2016**, *25*, 286–298. [CrossRef]
184. Moreno-Casasola, P.; Cejudo-Espinosa, E.; Capistrán-Barradas, A.; Infante-Mata, D.; López-Rosas, H.; Castillo-Campos, G.; Pale-Pale, J.; Campos-Cascaredo, A. Floristic composition, diversity and ecology of freshwater marshes in the central coastal plain of Veracruz, Mexico. *Bot. Sci.* **2010**, *87*, 29. [CrossRef]
185. Moreno-Casasola, P.; Rosas, H.L.; Mata, D.I.; Peralta, L.A.; Travieso-Bello, A.C.; Warner, B.G. Environmental and anthropogenic factors associated with coastal wetland differentiation in La Mancha, Veracruz, Mexico. *Plant Ecol.* **2009**, *200*, 37–52. [CrossRef]
186. Agraz-Hernández, C.M.; Chan-Keb, C.A.; Muñiz-Salazar, R.; Pérez-Balan, R.A.; Osti-Sáenz, J.; Gutiérrez-Alcántara, E.J.; Reyes-Castellano, J.E.; May-Colli, L.O.; Conde-Medina, K.P.; Ruiz-Hernández, J. Relationship between blue carbon and methane and the hydrochemistry of mangroves in South East Mexico. *Appl. Ecol. Environ. Res.* **2020**, *18*, 1091–1106. [CrossRef]
187. Saura, S.; Pascual-Hortal, L. A new habitat availability index to integrate connectivity in landscape conservation planning: Comparison with existing indices and application to a case study. *Landsc. Urban Plan.* **2007**, *83*, 91–103. [CrossRef]
188. Pascual-Hortal, L.; Saura, S. Comparison and development of new graph-based landscape connectivity indices: Towards the priorization of habitat patches and corridors for conservation. *Landsc. Ecol.* **2006**, *21*, 959–967. [CrossRef]
189. Saura, S.; Rubio, L. A common currency for the different ways in which patches and links can contribute to habitat availability and connectivity in the landscape. *Ecography* **2010**, *33*, 523–537. [CrossRef]
190. Zamora-Crescencio, P.; Mas, J.-F.; Rico-Gray, V.; Domínguez-Carrasco, M.R.; Villegas, P.; Gutiérrez-Báez, C.; Barrientos-Medina, R.C. Arboreal compostition and structure of the Petenes of the Petenes Biosphere Reserve, Campeche, Mexico. *Polibotanica* **2015**, *39*, 1–19.
191. Chan-Keb, C.; Agraz-Hernández, C.; Muñiz-Salazar, R.; Posada-Vanegas, G.; Osti-Sáenz, J.; Reyes Castellano, J.; Conde-Medina, K.; Vega-Serratos, B. Ecophysiological Response of Rhizophora mangle to the Variation in Hydrochemistry during Five Years along the Coast of Campeche, México. *Diversity* **2018**, *10*, 9. [CrossRef]
192. INEGI. CENSO SCINCE. 2020. Available online: https://censo2020.mx/ (accessed on 18 December 2021).
193. Goldberg, L.; Lagomasino, D.; Thomas, N.; Fatoyinbo, T. Global declines in human-driven mangrove loss. *Glob. Change Biol.* **2020**, *26*, 5844–5855. [CrossRef] [PubMed]
194. López-Portillo, J.; Zaldívar-Jiménez, A.; Lara-Domínguez, A.L.; Pérez-Ceballos, R.; Bravo-Mendoza, M.; Núñez Álvarez, N.; Aguirre-Franco, L. Hydrological Rehabilitation and Sediment Elevation as Strategies to Restore Mangroves in Terrigenous and Calcareous Environments in Mexico. In *Wetland Carbon and Environmental Management*; Krauss, K.W., Zhu, Z., Stagg, C.L., Eds.; Wiley: Hoboken, NJ, USA, 2021; pp. 173–190.
195. Wilson, M.H.; Ryan, D.G. Conservation of Mexican wetlands: Role of the North American Wetlands Conservation Act. *Wildl. Soc. Bull.* **1997**, *25*, 57–64.
196. Pérez-Arteaga, A.; Gaston, K.J.; Kershaw, M. Undesignated sites in Mexico qualifying as wetlands of international importance. *Biol. Conserv.* **2002**, *107*, 47–57. [CrossRef]
197. CONABIO. Manglares de México. Available online: https://www.youtube.com/watch?v=PQNYItdkiV0 (accessed on 18 December 2021).
198. AMEXID. *Informe Final del Proyecto "Intercambios de Conocimientos en el Uso de Datos de Satélite de Radar Y Ópticos en Los Ambientes Terrestres Y Marinos*; CONABIO: Ciudad de México, México, 2020.

199. DOF. *Protección Ambiental-Especies Nativas de México de Flora y Fauna Silvestres-Categorías de Riesgo y especificaciones para su Inclusión, Exclusión o Cambio-Lista de Especies en Riesgo*; NOM-059-SEMARNAT; Diario Oficial de la Federación de México: Ciudad de México, Mexico, 2010. Available online: https://dof.gob.mx/nota_detalle.php?codigo=5424575&fecha=05/02/2016 (accessed on 17 March 2022).
200. DOF. *Ley General de Vida Silvestre. Federación*; Diario Oficial de la Federación de México: Ciudad de México, Mexico, 2000; p. 72. Available online: https://www.gob.mx/cms/uploads/attachment/file/131763/29._LEY_GENERAL_DE_VIDA_SILVESTRE.pdf (accessed on 17 March 2022).
201. Justicia, S.C.d. Reseñas Argumentativas del Pleno y de las Salas. Reseña del Amparo en revisión 307/2016. Primera Sala de la Suprema Corte de Justicia de la Nación. "Derecho Humano a un ambiente sano y digno". 2018. Available online: https://www.scjn.gob.mx/sites/default/files/resenias_argumentativas/documento/2019-08/res-NLPH-0307-16.pdf (accessed on 17 March 2022).
202. HRO. Human Rights Office-Extract of the Amparo-307/2016. Supreme Court of Justice HRO. 2016. Available online: https://www.scjn.gob.mx/derechos-humanos/sites/default/files/sentencias-emblematicas/summary/2020-12/Summary%20AR307-2016%20HRO.pdf (accessed on 17 March 2022).
203. Romañach, S.S.; Deangelis, D.L.; Koh, H.L.; Li, Y.; Teh, S.Y.; Raja Barizan, R.S.; Zhai, L. Conservation and restoration of mangroves: Global status, perspectives, and prognosis. *Ocean. Coast. Manag.* **2018**, *154*, 72–82. [CrossRef]
204. Hamilton, S.E.; Casey, D. Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). *Glob. Ecol. Biogeogr.* **2016**, *25*, 729–738. [CrossRef]
205. Mondal, P.; Liu, X.; Fatoyinbo, T.E.; Lagomasino, D. Evaluating Combinations of Sentinel-2 Data and Machine-Learning Algorithms for Mangrove Mapping in West Africa. *Remote Sens.* **2019**, *11*, 2928. [CrossRef]
206. Adame, M.F.; Najera, E.; Lovelock, C.E.; Brown, C.J. Avoided emissions and conservation of scrub mangroves: Potential for a Blue Carbon project in the Gulf of California, Mexico. *Biol Lett.* **2018**, *14*, 20180400. [CrossRef]
207. Herrera-Silveira, J.A.; Pech-Cardenas, M.A.; Morales-Ojeda, S.M.; Cinco-Castro, S.; Camacho-Rico, A.; Caamal Sosa, J.P.; Mendoza-Martinez, J.E.; Pech-Poot, E.Y.; Montero, J.; Teutli-Hernandez, C. Blue carbon of Mexico, carbon stocks and fluxes: A systematic review. *PeerJ* **2020**, *8*, e8790. [CrossRef]
208. Alongi, D.M. Carbon sequestration in mangrove forests. *Carbon Manag.* **2012**, *3*, 313–322. [CrossRef]
209. Alongi, D.M. Carbon Cycling in the World's Mangrove Ecosystems Revisited: Significance of Non-Steady State Diagenesis and Subsurface Linkages between the Forest Floor and the Coastal Ocean. *Forests* **2020**, *11*, 977. [CrossRef]
210. Twilley, R.R.; Rovai, A.S.; Riul, P. Coastal morphology explains global blue carbon distributions. *Front. Ecol. Environ.* **2018**, *16*, 503–508. [CrossRef]
211. Alongi, D.M. Global Significance of Mangrove Blue Carbon in Climate Change Mitigation. *Sci* **2020**, *2*, 67. [CrossRef]
212. Ouyang, X.; Lee, S.Y. Improved estimates on global carbon stock and carbon pools in tidal wetlands. *Nat. Commun.* **2020**, *11*, 317. [CrossRef]
213. Rovai, A.S.; Twilley, R.R.; Castañeda-Moya, E.; Riul, P.; Cifuentes-Jara, M.; Manrow-Villalobos, M.; Horta, P.A.; Simonassi, J.C.; Fonseca, A.L.; Pagliosa, P.R. Global controls on carbon storage in mangrove soils. *Nat. Clim. Chang.* **2018**, *8*, 534–538. [CrossRef]
214. Vázquez-Lule, A.; Colditz, R.; Herrera-Silveira, J.; Guevara, M.; Rodríguez-Zúñiga, M.T.; Cruz, I.; Ressl, R.; Vargas, R. Greenness trends and carbon stocks of mangroves across Mexico. *Environ. Res. Lett.* **2019**, *14*, 075010. [CrossRef]
215. Ezcurra, P.; Ezcurra, E.; Garcillán, P.P.; Costa, M.T.; Aburto-Oropeza, O. Coastal landforms and accumulation of mangrove peat increase carbon sequestration and storage. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 4404–4409. [CrossRef]
216. Kumagai, J.A.; Costa, M.T.; Ezcurra, E.; Aburto-Oropeza, O. Prioritizing mangrove conservation across Mexico to facilitate 2020 NDC ambition. *Ambio* **2020**, *49*, 1992–2002. [CrossRef]
217. Aburto-Oropeza, O.; Ezcurra, E.; Danemann, G.; Valdez, V.; Murray, J.; Sala, E. Mangroves in the Gulf of California increase fishery yields. *Proc. Natl. Acad. Sci. USA* **2008**, *105*, 10456–10459. [CrossRef]
218. Thom, B.G. Mangrove Ecology and Deltaic Geomorphology: Tabasco, Mexico. *J. Ecol.* **1967**, *55*, 301–343. [CrossRef]
219. Rico-Gray, V.; Palacios-Rios, M. Leaf Area Variation in Rhizophora mangle L. (Rhizophoraceae) Along a Latitudinal Gradient in Mexico. *Glob. Ecol. Biogeogr. Lett.* **1996**, *5*, 30. [CrossRef]
220. Day, J.W.; Conner, W.H.; Ley-Lou, F.; Day, R.H.; Navarro, A.M. The productivity and composition of mangrove forests, Laguna de Términos, Mexico. *Aquat. Bot.* **1987**, *27*, 267–284. [CrossRef]
221. Lopez-Portillo, J.; Ezcurra, E. Los manglares de Mexico. *Madera y Bosques* **2002**, *8*, 27–51. [CrossRef]
222. Rivera-Monroy, V.H.; Twilley, R.R.; Mancera, E.; Alcantara-Eguren, A.; Castañeda-Moya, E.; Casas-Monroy, O.; Reyes, F.; Restrepo, J.; Perdomo, L.; Campos, E.; et al. Adventures and misfortunes in Macondo: Rehabilitation of the Cienaga Grande de Santa Marta Lagoon Complex, Colombia. *Ecotropicos* **2006**, *19*, 72–93.
223. Gittman, R.K.; Baillie, C.J.; Arkema, K.K.; Bennett, R.O.; Benoit, J.; Blitch, S.; Brun, J.; Chatwin, A.; Colden, A.; Dausman, A.; et al. Voluntary Restoration: Mitigation's Silent Partner in the Quest to Reverse Coastal Wetland Loss in the USA. *Front. Mar. Sci.* **2019**, *6*, 511. [CrossRef]
224. Peyronnin, N.; Green, M.; Parsons Richards, C.; Owens, A.; Reed, D.; Chamberlain, J.; Groves, D.G.; Rhinehart, W.K.; Belhadjali, K. Louisiana's 2012 Coastal Master Plan: Overview of a science-based and publicly Informed decision-making process. *J. Coast. Res.* **2013**, *67*, 1–15. [CrossRef]

225. Merino, J.; Aust, C.; Caffey, R. Cost-Efficacy in Wetland Restoration Projects in Coastal Louisiana. *Wetlands* **2011**, *31*, 367–375. [CrossRef]
226. Bayraktarov, E.; Saunders, M.I.; Abdullah, S.; Mills, M.; Beher, J.; Possingham, H.P.; Mumby, P.J.; Lovelock, C.E. The cost and feasibility of marine coastal restoration. *Ecol. Appl.* **2016**, *26*, 1055–1074. [CrossRef]
227. Abelson, A.; Reed, D.C.; Edgar, G.J.; Smith, C.S.; Kendrick, G.A.; Orth, R.J.; Airoldi, L.; Silliman, B.; Beck, M.W.; Krause, G.; et al. Challenges for Restoration of Coastal Marine Ecosystems in the Anthropocene. *Front. Mar. Sci.* **2020**, *7*, 544105. [CrossRef]