Fragmentation of the mangrove forest in Marismas Nacionales, Mexico, from 1981 to 2015

Fragmentation de la forêt de mangroves dans les Marismas Nacionales, au Mexique, de 1981 à 2015

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ABSTRACT: The objective of this research is to estimate the fragmentation of the mangrove forest landscape in Marismas Nacionales, Mexico, using landscape ecology metrics (number of patches per class, number of patches of each class in the landscape, average patch size, relative amount of edge in the landscape, weighted area of the average fractal dimension of the patch). At the same time, the factors that cause fragmentation promoted by deforestation and degradation were also determined, for which a specific survey was generated for the mangrove forest that can later be applied in any study area, through published literature and experts in the subject. The fragmentation of the mangrove forest was obtained in the course of the years 1981-2015 by increasing its patches and decreasing its edges, regarding the factors that caused deforestation was due to anthropogenic activities mainly by the expansion of infrastructure and aquaculture, while degradation was caused by natural causes such as hurricanes and tropical storms.
KEY WORDS: Mangrove, fragmentation, causal factors.

RÉSUMÉ : Cet article a pour objectif d'évaluer la fragmentation du paysage de mangrove à Marismas Nacionales, au Mexique, à l'aide d'indicateurs d'écologie du paysage (nombre de parcelles par type, nombre total de parcelles, taille moyenne des parcelles, longueur relative des bordures, dimension fractale moyenne pondérée des parcelles). Parallèlement, les facteurs de fragmentation liés à la déforestation et à la dégradation ont été identifiés. Pour ce faire, un questionnaire spécifique aux mangroves a été élaboré, pouvant être appliqué ultérieurement à d'autres zones d'étude. Les données ont été collectées à partir de la littérature scientifique et auprès d'experts du domaine. La fragmentation de la mangrove a été observée entre 1981 et 2015, avec une augmentation du nombre de parcelles et une diminution de la longueur des bordures. Les facteurs de déforestation étaient principalement d'origine anthropique, notamment l'expansion des infrastructures et l'aquaculture, tandis que la dégradation était due à des phénomènes naturels tels que les ouragans et les tempêtes tropicales.
MOTS CLÉS : Mangrove, fragmentation, facteurs causaux.

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1. Introduction

In the last 20 years, the mangrove forest has suffered prolonged pressures, as globally about 20% of the total area has been lost to deforestation (FAO, 2007; Rossi et al., 2020). Likewise, according to the FAO (2023) from 2000 to 2020, more than 284,000 hectares of mangroves were lost. At the same time, the degraded area has increased, so these forests are at risk of being lost. One of the areas with the greatest extension of mangrove forests in the world is Mexico, representing 6% of the total mangrove forests worldwide, making it the fourth country with the greatest extension (CONABIO, 2022). However, despite the large mangrove extensions, 80, 850 ha have been lost and 17, 140 ha of forest have suffered degradation in the period 1970-2015 (Valderrama-Landeros et al., 2017) .

It should be noted that the Marismas Nacionales region has multiple national and international conservation designations, such as: International Western Hemisphere Shorebird Network Site (1992); Priority Marine Conservation Area (2005); Priority Marine Region (1998); Priority Terrestrial Region (2000); Priority Hydrological Region (2002); Important Bird Conservation Area (1998); Marismas Nacionales Nayarit Biosphere Reserve (2010) (Blanco et al. 2011); and the Marismas Nacionales Nayarit Biosphere Reserve (2010) (Blanco et al., 2011).

In addition, the largest extension of mangroves in the Mexican Pacific is located in Marismas Nacionales, hosting great biodiversity, including endangered species (Cárdenas, 2011) such as mangroves according to the NOM-059-SEMARNAT-2010 (2010), with respect to the species of fish, crustaceans, and bivalve mollusks that inhabit there and economically contribute $80 million pesos per year locally and $13.5 million dollars regionally (CONANP, 2016). However, the natural resources have been exploited to the extent of positioning it as a site with biological relevance and in need of ecological rehabilitation, decreed by CONABIO (Valdez-Hernández et al., 2009).

There are several factors that cause both deforestation and degradation of mangroves which promotes an ecological assessment of the landscape, spatial patterns of patches, cover classes, indices to determine the characteristics of fragmentation and threats to the ecosystem (CONABIO, 2021). Landscape fragmentation decreases the viability and dispersion of populations, negatively affecting the conservation of biodiversity, affecting the functioning of flora and fauna, manifesting biotic and abiotic changes, alteration of the microclimate, increased hunting, selective logging and fires, as well as the risk of zoonoses and public health diseases (Arasa-Gisbert et al., 2021; Bustamante and Grez, 1995; Hernández-Pérez et al., 2022; Leija and Mendoza, 2021).

Some methods used to perceive landscape fragmentation have been based on the comparison of maps from different dates (Salas et al., 2019) also, through the delimitation of landscape units based on the correlation of natural and social variables of the geosystem (Canchola-Pantoja, 2017) and in landscape metrics of temporal maps to assess changes in the dynamics and structure of the landscape (Kanniah et al., 2021; Romero-Berny et al., 2015; Villatoro-arreola et al., 2022).

Continuing with the causes of mangrove deforestation and degradation, the main reason is anthropogenic factors, since according to published literature, the main causes of mangrove loss and degradation in the world are the increase of the agricultural and livestock frontier, the construction of tourism developments, urban development and the construction of shrimp farms (Benavides et al., 2015; Berlanga-Robles, 2007; Buendía-Buendía et al., 2021; Hirales-Cota et al., 2010; Kanniah et al., 2021; MARN, 2013; Rodríguez-Zúñiga et al., 2013; Vega-Vela et al., 2018; Villatoro-arreola et al., 2022; Zhiminaicela-Cabrera et al., 2020).

Likewise, it is worth mentioning that there are also environmental factors that impact mangroves such as hurricanes, tropical storms, fires, the El Niño phenomenon, natural changes in hydrology, etc. (Asbridge et al., 2019; Harada et al., 2020; Lagomasino et al., 2020). Finally, there are socioeconomic factors that motivate this to occur, since the red mangrove is mainly used for sale as poles or for firewood, in addition to being exploited by the growing market for fish, crustaceans and mollusks, coupled with the lack of knowledge of the importance of the forest, the lack of programs and public policies for its conservation (Kanniah et al., 2021; SEMARNAT and CONANP, 2013; Setiyaningrum, 2019; Zavala, 2017).

In order to understand the causal factors that influence forest processes such as deforestation, degradation and natural recovery, opinion surveys have been used, particularly the one proposed by Geist and Lambin (2002), however, it is limited to know in greater detail a particular forest, there are also specific surveys in this case for the mangrove forest only that are applied exclusively to the study areas that investigate (Hirales-Cota et al., 2010; Zavala, 2017).

Therefore, the objective of this research is to estimate the fragmentation of the mangrove forest landscape using the official Mexican cartography generated by CONABIO through landscape ecology metrics. At the same time, the factors that cause fragmentation promoted by deforestation and degradation were also determined, for which a specific survey was generated for the mangrove forest that can later be applied in any study area. The survey was elaborated through a bibliographic exploration of implemented methodologies and factors that promote these forest processes, with the purpose of generating qualitative and quantitative information that can be used to make new decisions for public programs and policies.

2. Study area

The mangrove forest present in Marismas Nacionales (MN) is the largest in the eastern Pacific (figure 1), hosting migratory birds, 99 endemic species and 73 threatened or endangered species (Cárdenas-Guzmán, 2011).It covers an area of 220,000 ha and includes the municipalities of Acaponeta, Santiago Ixcuintla, Rosamorada, San Blas, Tuxpan and Tecuala in the state of Nayarit and Escuinapa in the state of Sinaloa, as well as the Bejuco, Cañas, Acaponeta, San Pedro Ruíz rivers and the Pacific Ocean. It has an average annual temperature of 22°C with a predominantly warm sub-humid climate (Valdez-Hernández et al., 2009). With a population of 56, 349 inhabitants (INEGI, 2015). MN was decreed Ramsar site No. 732 in 1995, in 1998 important area for bird conservation and in 2010 Protected Natural Area Biosphere Reserve Marismas Nacionales, Nayarit (SEMARNAT and CONANP, 2013).

3. Methods

In order to know the fragmentation of the mangrove forest, we used the maps of land use and vegetation cover of the coastal zone associated with mangroves which were acquired through the cartography published by CONABIO from the dates 1981, 2005 and 2015 at a scale of 1:50,000, represented by eight categories (table 1) (CONABIO, 2016):

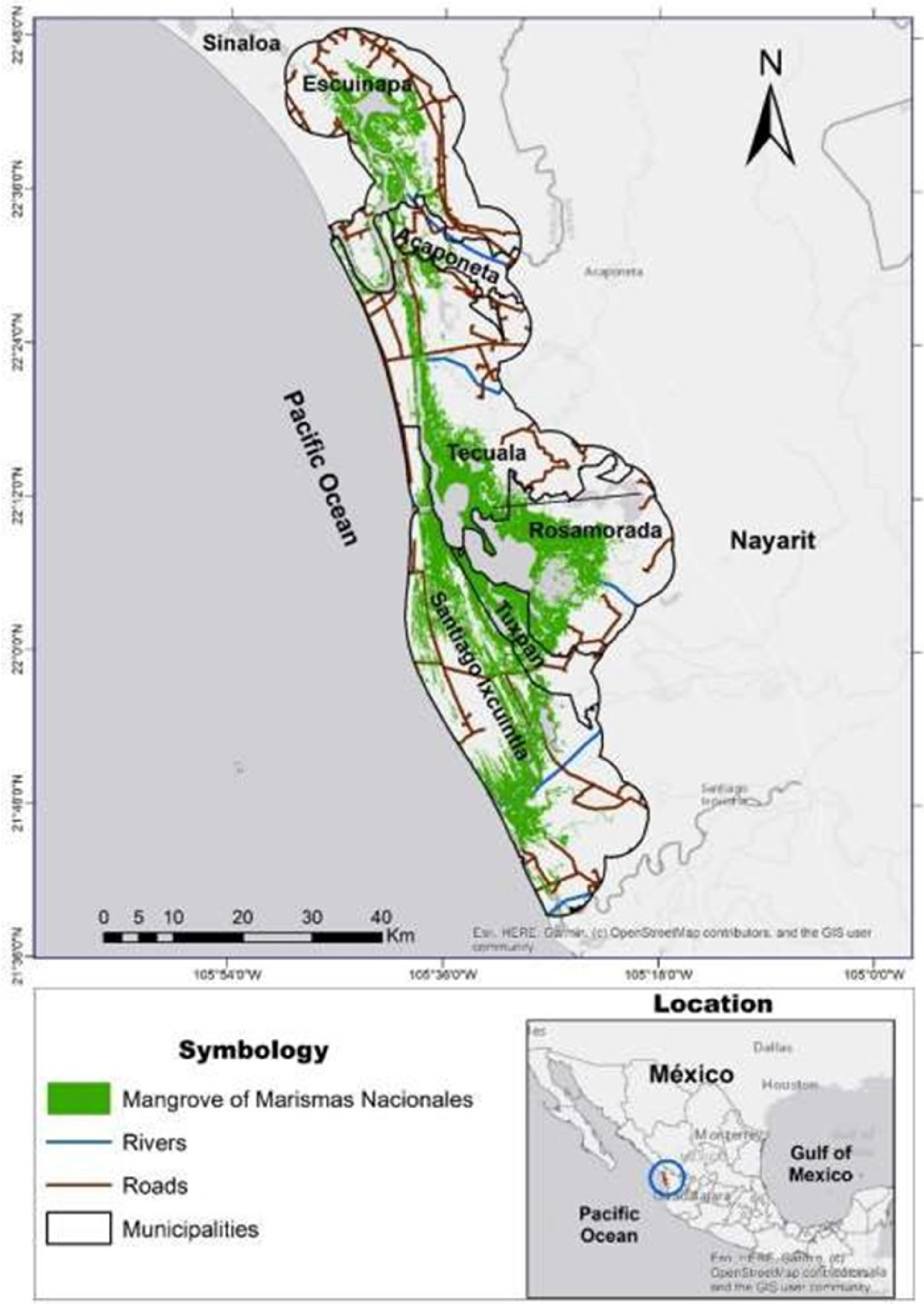

Figure 1 Study área. Mangrove of Marismas Nacionales of 2015.

Table 1 Description of land use and vegetation categories at Marismas Nacionales (CONABIO, 2016).

Category	Features
Anthropic development	Includes towns, aquaculture ponds, shrimp farms, salt ponds, roads and highways, as well as hydraulic infrastructure works including canals.
Agriculture-Livestock	Includes land used for rainfed and irrigated agriculture and pastures dedicated to livestock. This category corresponds to anthropic covers destined to food production, as well as perennial tree monocultures specific to each region, and other agroecosystems. It includes resting agricultural areas.
Low and medium rainforests	Includes shrub and tree vegetation of flooded lowland evergreen and sub evergreen forests and flooded medium sub evergreen forests, different types of secondary tree and shrub vegetation and secondary herbaceous vegetation.
No vegetation	Includes areas with no apparent vegetation and erosion, coastal sand dunes and beaches.
Mangrove	Includes shrub and tree wetlands formed by the vegetative association of one or more mangrove species: white mangrove (*Laguncularia racemosa*), red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*).
Disturbed mangrove	Includes wetlands consisting of patches of dead or regenerating mangrove trees and/or shrubs. This category refers to forest cover disturbed by hurricanes, storms, cyclones and by the construction of hydraulic infrastructure, highways and roads.
Other wetlands	It includes the hydrophilic vegetation of Popal-Tular-Carrizal, in addition to flooded grasslands, hydrophilic or halophilic vegetation with scattered mangrove individuals or on small islands and coastal saline soils with little vegetation cover.
Water bodies	Includes oceans, bays, estuaries, lagoons, rivers, dams, cenotes, water holes.

3.1. Mangrove forest landscape fragmentation analysis

This cartography was rasterized considering a pixel size of 100 x 100, then the metrics were estimated for the eight categories (classes) belonging to each map, using the specific tool for the ecological analysis of the landscape "Spatial statistics (FragStats Interface)" of the Patch Grid module in ArcGis 10.1, which were number of patch per class (NUMP): number of patches or fragments of each class in the landscape; average patch size (MPS): area occupied by a patch (hectares); relative amount of edge in the landscape (ED): relative amount of edge length of each class in the landscape (Km^2), using the following formula: $ED = TE / TLA$ Where: TE corresponds to the sum of the edge perimeter per class and TLA the sum of areas of all patches in the landscape.

The sum of the edge perimeter per class (TE): length of the edge perimeter of each class (Km^2); weighted area of the average fractal dimension of the patch (AWMPFD): average fractal dimension of the patch with the addition of the individual patch area weighting applied to each patch, because larger patches tend to be more complex than smaller ones, thereby having the effect of determining the complexity of the patch regardless of its size (Unit of measure: When the average fractal dimension is close to 1 they are shapes with simple perimeters and if it is close to 2 the shapes are more complex) (McGarigal et al., 2023).

3.2. Causal factors of mangrove forest fragmentation

In order to understand the causal factors of mangrove forest fragmentation in MN, a survey was generated specifically for this forest, which can be applied to any area of interest for research.

This survey was carried out through a bibliographic analysis acquiring information on the methodological contributions that generate knowledge about mangroves, such as the analysis of literature published by experts (Geist and Lambin, 2002), future vision analysis and exploratory data analysis. As well as the type of sampling, the ideal sampling is by coexistence, selecting respondents who are experts in the field belonging to governmental departments such as the Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA), the Secretariat of Environment and Natural Resources (SEMARNAT), the National Commission of Natural Protected Areas (CNPA), and the National Commission of Natural Protected Areas (CNPA), Comisión Nacional de Áreas Naturales Protegidas (CONANP), Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), Comisión Nacional Forestal (CONAFOR), academic sector Universidad Autónoma de Sinaloa (UAS), private sector (environmental consultancies) and local population of the study area, particularly those responsible for fishing cooperatives and fishermen.

In parallel, the appropriate type of analysis to implement in this opinion survey was investigated. In addition, empirical data were acquired that promote deforestation and degradation of this forest at the global, regional and local levels (MN). With the information obtained, the survey was designed and applied to 56 experts on the subject, and the statistical analysis of frequency was carried out, generating qualitative and quantitative information useful for public policy decision making.

The opinion survey consisted of the following aspects: information on the importance of mangrove forests, the benefits that experts on the subject have acquired, what type of activities are carried out in this forest, what are the anthropogenic, environmental, economic, and social factors that cause deforestation and degradation, if there has been an increase in area and what has caused it, what is the vision for mangrove forests for the year 2030, and the guidelines that should be followed to increase the area of this forest in the future.

It should be noted that this survey was prepared virtually to optimize the response time of the respondents, for this purpose a database of experts belonging to government agencies, private and academic sector was generated where data such as name, job title, telephone and email were obtained, published in the services of the corresponding web pages. With respect to the experts in

charge of the cooperatives and fishermen in the study area, the survey was carried out in person to each one of them in order to know their perspective of the mangrove by interacting directly with this forest.

4. Results and discussion

4.1. Landscape fragmentation analysis in Marismas Nacionales

The MN landscape ecology analysis showed eight types of classes in the different dates evaluated, in which we can observe that the number of patches belonging to the Mangrove cover was increasing, since in 1981 there were 682 with an average patch size of 117.28 ha, by 2005 they increased to 825 representing a size of 89.75 ha and in 2015 there were 747 with an average of

94.86 ha, indicating that the landscape has been fragmenting. This was also observed in the number of disturbed mangrove patches by increasing from 31 to 133 as well as their average size from 24.68 ha to 29.84 ha respectively (table 2).

Continuing with the analysis, it was observed that the MN vegetation covers have shown fragmentation over the years, such that, Low and medium forests in 1981 had 1372 patches, by 2005 2113 and in 2015 2078, decreasing their average patch size from 33.37, 16.75 and 14.89 respectively for each year evaluated. The same occurred with the Other wetlands class by increasing their number of patches from 990 to 1499, reducing their average size from 49.36 to 25.79 (table 2).

This fragmentation may have originated due to the decrease of patches of the Agricultural-livestock class, which in turn increased its average size and became more complex, allowing it to become the most representative class in the MN landscape. In addition, the anthropogenic development class presented an increase in patches over the years from 742 to 1286 with an increase in average patch size indicating that patches of this class influence the fragmentation of the MN vegetation (table 2).

Table 2 Number of patches per class (NUMP) and average patch size per class (MPS) in Marismas Nacionales.

Types of patches	NUMP			MPS (Ha)		
	1981	2005	2015	1981	2005	2015
Anthropic development	742	1274	1286	3.37	6.25	9.64
Anthropic development	477	587	471	149.24	146.77	187.47
Low and medium jungles	1372	2113	2078	33.37	16.75	14.89
Without vegetation	166	146	153	6.2	5.36	4.58
Mangrove	682	825	747	117.28	89.75	94.86
Disturbed mangrove	31	117	244	24.68	38.44	29.84
Other wetlands	990	1236	1499	49.36	35.64	25.79
Water	1910	2065	2341	24.4	21.33	20.41

Continuing with the results, the following table 3 shows how the fragmentation of the patches occurred at the edge of the patches, affecting their interior by decreasing their average size in the years 2005 and 2015. This edge fragmentation was visualized as follows because in 1981 there were 4,978 Km^2 representing 0.1678 Km^2 in the landscape, indicating this value that the perimeter shape is complex as its unit of measurement is greater than 2 (Table 4), in 2005 it decreased to 4,871 Km^2 corresponding to 0.1641 Km^2 and for 2015 it was 4,600.6 Km^2 with 0.1549 Km^2 (table 3).

In addition to what happened, the disturbed mangrove edges increased considerably over the years, so that in 1981 there were only 76.4 km^2 representing 0.0026 Km^2 of the landscape, in 2005 it was 469.2 km^2 with 0.158 Km^2 (Table 3) these two dates presented a simple perimeter shape by obtaining an average fractal dimension value of less than 2 (Table 4), and by 2015 the perimeter shape became complex by reaching 0.262 Km^2 with 778.2 Km^2 (table 3).

Table 3 Sum of edge perimeter by class (TE) and relative amount of edge length of each class in the landscape (ED) in Marismas Nacionales.

	TE (Km^2)			**ED (Km^2)**		
Classes	1981	2005	2015	1981	2005	2015
Anthropic development	496	1027.6	1327.2	0.0167	0.0346	0.0447
Livestock-agricultural	3989	4643.8	4477.4	0.1344	0.156	0.1508
Low and medium jungles	4408.4	4380.8	4056.2	0.1486	0.1475	0.1366
Without vegetation	231.8	193	180.2	0.0078	0.0065	0.0061
Mangrove	4978	4871.4	4600.6	0.1678	0.1641	0.1549
Disturbed mangrove	76.4	469.2	778.2	0.0026	0.158	0.262
Other wetlands	4553.8	4499.8	4733.6	0.1535	0.1515	0.1594
Water	3876.6	3862.8	4316.6	0.1306	0.1301	0.1454

Weighted area of the mean fractal dimension of the Marismas Nacionales landscape patches.

		AWMPFD	
Classes	1981	2005	2015
Anthropic development	1.05	1.06	1.09
Livestock-agricultural	1.25	1.27	1.26
Low and medium jungles	1.19	1.17	1.15
Without vegetation	1.13	1.11	1.11
Mangrove	1.29	1.31	1.31
Disturbed mangrove	1.13	1.22	1.2
Other wetlands	1.24	1.23	1.22
Water	1.19	1.19	1.19

4.1.1. Discussion of landscape fragmentation analysis in Marismas Nacionales

During the years evaluated 1981, 2005 and 2015 in MN there has been a fragmentation of the mangrove forest by increasing the number of patches and decreasing their average size, in additionto this the affection has been manifested on the edges of the patches towards the interior of the same. This places the coexisting biodiversity at risk, such as the survival of 99 endemic species and 73 threatened or endangered species, including *R. mangle, L. racemosa and A. germinans*, and this fragmentation increases the risk of local extinction in the long term (Cárdenas-Guzmán, 2011).

These results are consistent with the study by Romero-Berny et al. (2015) conducted in the Soconusco Region, Chiapas in finding negative trends in the area and total edge indices, as they observed a progressive reduction in patch area, indicating mangrove fragmentation. For this research they used the metrics of number of patches, mean patch size, mean patch edge, shape index and fractal dimension.

Something similar occurred in southern Peninsular Malaysia when analyzing fragmentation with the following metrics class area (CA), total landscape area (TLA), number of patches (NP), mean patch size (MPS), total edge (TE), edge density (ED), mean shape index (MSI), average weighted MSI (AWMSI), average perimeter area ratio (MPAR) and average patch fractal dimension (MPFD), they found a reduction in mean patch size, an increase in the number of mangrove patches, as well as shape complexity, where smaller and more isolated mangrove patches were shown. This was due to the transition of surface area to human activities, plantations, and aquaculture (Kanniah et al., 2021).

On the other hand, Villatoro-arreola et al. (2022) in their research found fragmentation processes with a low degree of modification by observing a decrease in the mean size and total edge of mangrove patches in the Chantuto-Panzacola lagoon system, Chiapasa, Mexico, when analyzing the following landscape metrics: patch number, mean patch size, standard deviation of patch size, total edge, edge density, Shannon diversity index, Shannon evenness index, and fractal dimension of the mean patch. This occurred when the productive activities of permanent plantations increased, influencing the management policies committed to when La Encrucijada Biosphere Reserve was decreed in 1995, which can cause problems in the functioning of the system, particularly the mangrove.

On the other hand, Salas et al. (2019) when analyzing the size of patches obtained a decrease of 66% of mangrove due to the impact of a hurricane in the Cayos Miskitos Reserve, and in their last evaluated date corresponding to the year 2017 there was an increase in patches when the forest regenerated naturally. However, the landscape remains fragmented. In this context, it should be noted that the mangrove can recover naturally in a period of approximately five years as long as the condition has been caused naturally, such as natural phenomena (Valderrama-Landeros et al., 2017).

In relation to this issue, in MN, particularly in the municipalities of Tecuala and Santiago Ixcuintla, in the state of Nayarit. Ramírez-Bojórquez et al. (2005) showed a fragmented coverage and a decrease in mangrove connectivity by obtaining an increase in the number of patches and a reduction in their size when they analyzed the following metrics number and mean patch size and the major patch index. This fragmentation occurred due to anthropogenic activities specifically aquaculture, localities and road infrastructure.

4.2. Causal factors of landscape fragmentation in Marismas Nacionales

In relation to the results obtained from the factors that caused the fragmentation of the mangrove forest about the 56 cases of studies conducted during the months of December 2019 to February 2020 recognized the importance of the mangrove forest, experts in the field mentioned that they are very useful for the breeding of fish, mollusks, shrimp and other crustaceans, also referred to the environmental, social and economic relevance they provide, so they suggested that these forests have a wide field of research.

They also mentioned the benefits that the local population obtained from the mangrove forest in MN, mainly fish or other animals for consumption and sale, coinciding 73.21% of respondents, to a lesser extent they used firewood (only 19.64% corresponding to fishermen) indicated that it was for cooking or heating their food during the day when they were fishing. It is important to clarify that the wood used for the construction of roofs or fences (10.71%) was before the mangrove protection came into effect in the area, so most respondents answered "Null", as well as medicinal products, and some of the fishermen reported that they used mangrove tannins to paint their fishing nets.

Regarding the activities carried out in the mangrove swamp and its surroundings, the most relevant in MN were fishing (78.57% of respondents agreed), which generated economic income and welfare for the surrounding population, another was the boat ride (85.71%) to meet the fishing day and to carry out tourism and ecotourism and bird watching (87.5%).

Continuing with the respondents' perspective on how the mangrove forest has reflected in recent years, all shared the opinion on the deforestation that this forest has presented, as well as 96.43% of the participants pointed out a significant increase of disturbed mangrove and only 21.43% reported that the mangrove area increased.

The causal factors of deforestation are shown below, starting with the anthropogenic causes (figure 2), where the most relevant promoting actions of this process were obtained, of which the predominant one was the expansion of infrastructure according to 91.07% of the case studies, followed by aquaculture (87.5%) and free fishing (67.86%).

Meanwhile, agricultural and livestock activities had a slight influence on mangrove deforestation, but increased their potential influence when a natural phenomenon occurred (hurricanes or tropical storms) when agrochemical fertilizers and fecal waste from livestock ran off into the marshes, causing physiological stress to the mangrove plants, as reported by fishermen in the study area.

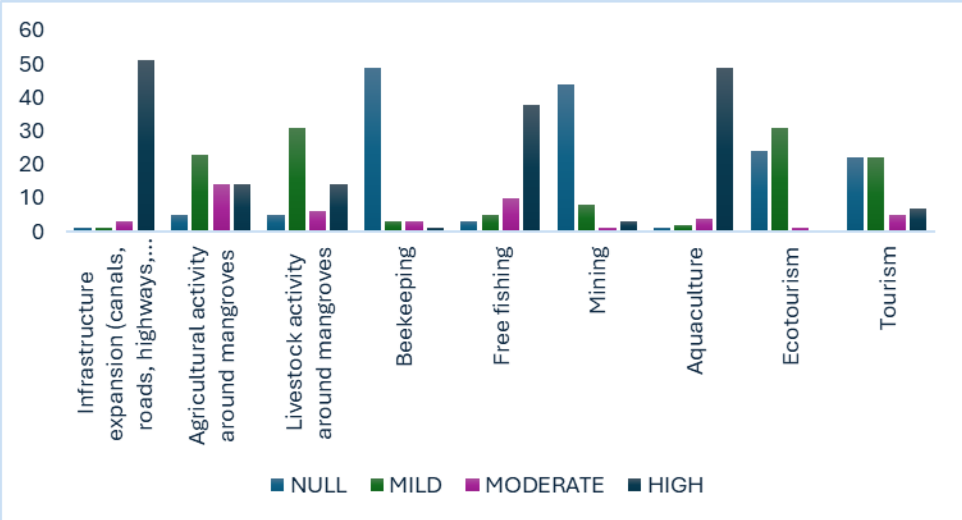

Figure 2 Anthropogenic factors influencing mangrove forest deforestation in Marismas Nacionales.

The environmental factors (figure 3) influencing mangrove deforestation in MN were mainly hurricanes (85.71%), followed by tropical storms (80.36%) and pollution (71.43%), the latter being especially related to the runoff of agrochemicals used in agricultural production mentioned above. On the other hand, high temperatures influenced mangrove growth and development, data obtained by respondents.

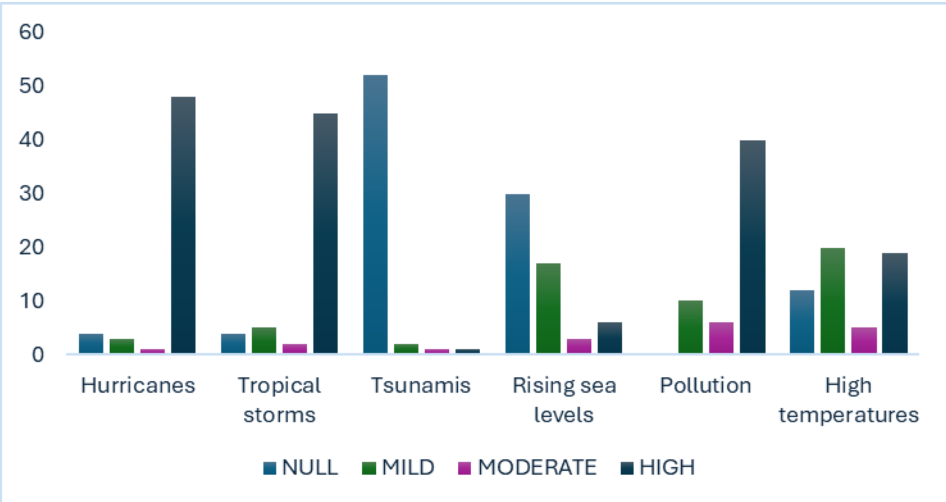

Figure 3 Environmental factors influencing mangrove forest deforestation in Marismas Nacionales.

Another event responsible for deforestation, related to economic factors (figure 4), was the regional commercialization of fish, crustaceans and mollusks (62.50%), followed by the growth of the local market for these same species (35.71%). The agricultural and livestock market had a low impact, i.e., between none and slight.

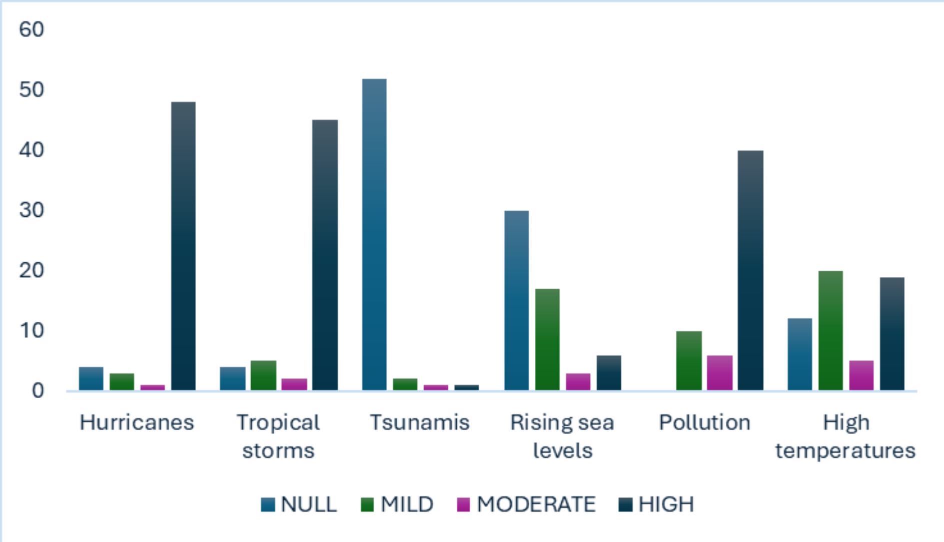

Figure 4 Economic factors influencing mangrove forest deforestation in Marismas Nacionales.

Subsequently, the social factors with negative repercussions were the lack of public programs and policies for the conservation of mangrove forests according to 85.71% of the cases, also the lack of knowledge of the surrounding population about the importance of the forest (82.14%) and on a lower average but still important and potentially influential was the lack of interest of the population (66.07%) to conserve mangroves (figure 5).

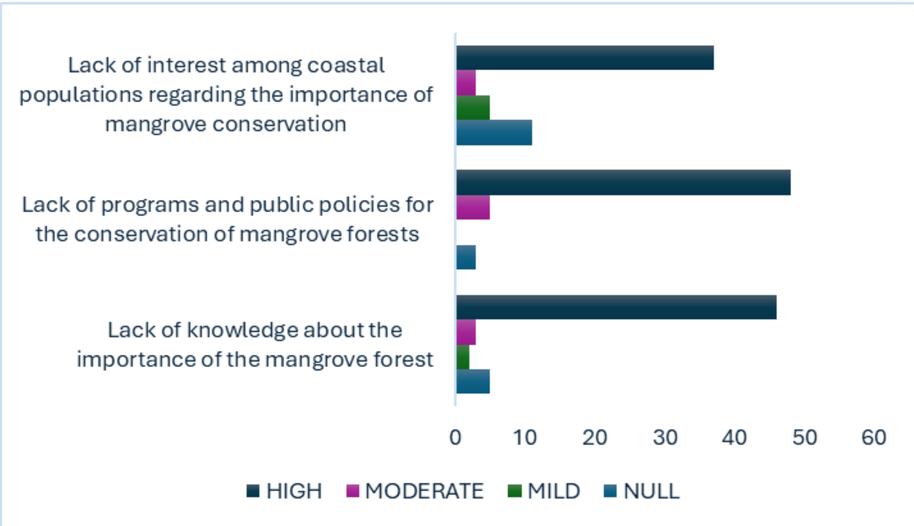

Figure 5 Social factors influencing mangrove forest deforestation in Marismas Nacionales.

In relation to, the causes that provoked the degradation (figure 6) was mainly due to environmental conditions (76.79%) such as hurricanes and tropical storms that have impacted MN mainly in the municipality of Escuinapa, Sinaloa, as well as increasing the economy (25%) of the site, to improve the quality of life of the population (21.43%) this was more noticeable in the municipalities of the State of Nayarit.

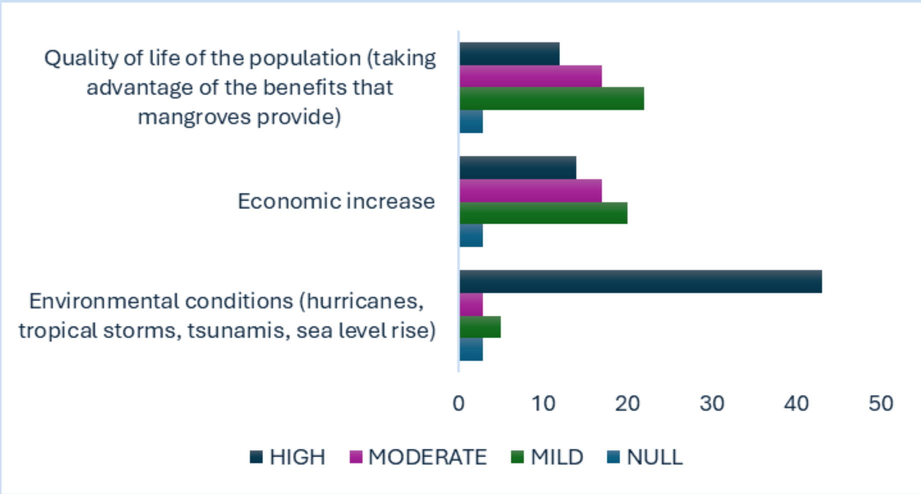

Figure 6 Factors influencing mangrove forest degradation in Marismas Nacionales.

Among the case studies that observed an increase in mangrove area in recent years, it was promoted by reforestation programs (66.67%), as well as public programs and policies that have been implemented to conserve the forest (66.67%). It is also important to mention the opinion about the natural growth of the mangrove forest, which ranged from null to slight, and only 33.33% had the perspective of a possible natural recovery (figure7).

The next point dealt with the vision that the experts in the subject have of how the mangrove forest surface will be in 2030, obtaining that 66.07% visualized a high increase in the disturbed mangrove surface, 53.57% reported that the mangrove will tend to increase highly and 48.21% warned that the surface will decrease moderately (figure7).

Regarding the guidelines to be followed to increase the mangrove area, they suggested increasing reforestation programs (92.86%), improving public policies for the conservation and management of mangrove forests (83.93%) in order to extend their sustainable management and in turn generate better economic income and quality of life for the local population, since natural regeneration (32.14%) has been very low in recent years (figure7).

Therefore, they mention that the mangrove alone could not recover due to the fragmentation of the landscape that has occurred, emphasizing that one of the fruitful solutions would be to reforest more mangrove areas and carry out hydrological restoration in affected areas due to the increase of infrastructure (canals, roads and highways) that have affected the natural hydrological flow causing the water not to flow to places where it normally occurs, causing mangrove plant mortality (figure7).

Within this analysis of causal factors of deforestation and degradation of the mangrove forest, an estimated model of the causes of the forest processes was generated, with respect to the data acquired in the survey of the perspective of the experts in the subject, represented in percentages, providing an idea of how the anthropogenic, environmental, economic, social and political causal factors influence the forest processes of the mangrove forest in Marismas Nacionales (figure7).

From this model it can be mentioned that the greatest deforestation of the mangrove forest is due to anthropogenic causes such as the expansion of infrastructure with 10.06% followed by aquaculture with 9.66%, this is driven by social factors due to the lack of public programs and policies for conservation (9.47%).47%), as well as the lack of knowledge of the surrounding population about the importance of mangroves (9.07%), another precursor are economic factors in order to increase regional (6.90%) and local (4.73%) fishing trade, and political factors with the inaccuracy of improving public policies for the conservation and sustainable management of mangroves (9.27%) (figure7).

The model indicates that mangrove degradation has been driven mainly by environmental causes such as hurricanes (13.60%) and tropical storms (12.75%). It also suggests that there is a 32.14% probability of mangrove area increase due to natural regeneration, but in order to increase this area in Marismas Nacionales, more reforestation programs should be implemented (92.86%), as shown in figure 7.

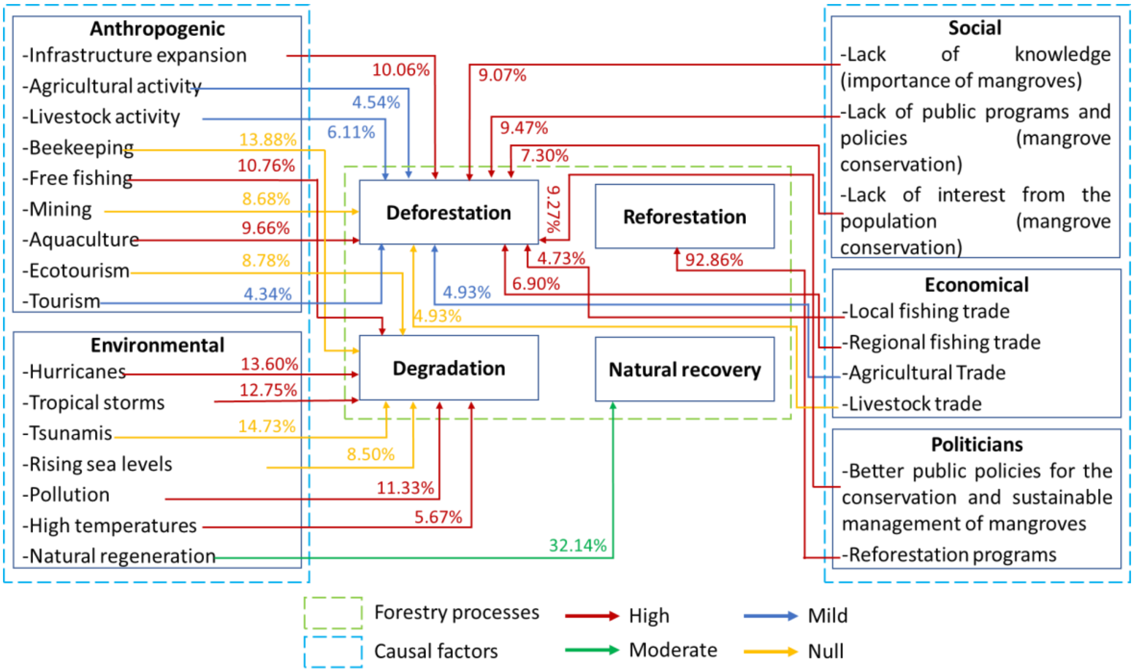

Figure 7 Causal factors of mangrove forest processes in Marismas Nacionales.

4.1.1 Discussion of the causal factors of landscape fragmentation in Marismas Nacionales

The causal factors promoted by anthropogenic cause that have been reported in MN have been due to the increase of infrastructure such as canals, roads and highways, as well as aquaculture, livestock, agriculture (Benavides et al., 2015; Berlanga-Robles, 2007; Hirales-Cota et al., 2010; MARN, 2013; Rodríguez-Zúñiga et al., 2013; Vera A., 2018). Another report has been for hydrological modification, political and health aspects, contamination, and unsustainable harvesting in order to reactivate the region's economy (SEMARNAT and CONANP, 2013).

Regarding the methodologies used to determine the factors that affect the mangrove forest, it was observed that the studies carried out are not specific, since the most widely implemented methodology in the forestry area and in the REDD+ Reducing Emissions from Deforestation and Forest Degradation strategy is the one proposed by (Geist and Lambin, 2002) only, this is used to know the main and underlying causes that promote deforestation of all tropical forests in the world and not specifically of a forest, which may vary with respect to the utility and benefits that each forest provides.

However, methods have also been implemented to determine the causes that specifically affect the mangrove forest, such as the one proposed by Hirales-Cota (2009) in which through the semi-structured survey applied acquired knowledge about how deforestation has been in the coastal zone of Mahahual-Xcalak Quintana Roo, on the other hand. Zavala (2017) obtained the cause of this forestry process in Huaylá, Machala, Ecuador through the semi-structured survey she elaborated based on published literature as well as a participatory backasting with the respondents.

In addition, the survey generated by Setiyaningrum (2019) serves for public policy decision making in order to promote and preserve the mangrove ecosystem in Dukuh Bendo, Jatikontal Village, Purwodadi District, Purworejo Regency, Central Java.

In this sense, it is important to clarify that these methodologies implemented particularly in the mangrove forest are elaborated to be applied in the study areas of the aforementioned authors, making their application to other regions difficult, and only show the causes of deforestation, future perspectives and perceptions of sustainability, without addressing the forest degradation process that has been very relevant in the increase of surface area in recent years both locally and globally, putting the integrity of the mangrove forest at risk.

Therefore, in order to provide a medium and long term solution for the conservation and increase of mangrove forest area, an integrated methodology should be implemented that can be applied in any area where this forest exists, and that this methodology should provide information on the causes that promote deforestation and degradation, the perspective on the importance of this forest, as well as the future projection that experts on the subject visualize.

5. Conclusion

The landscape metrics used show how the mangrove forest in Marismas Nacionales has been fragmenting during the years 1981 to 2015, increasing its patches, at the same time that these patches were decreasing their edge so that the fragmentation is directed to the interior of the patches, affecting the biodiversity that these harbor.

With respect to the proposed methodology for understanding the causal factors of deforestation and degradation of the mangrove forest, it provided concrete data and scientific evidence on the causes of these forest processes, the perspective of experts on the subject of how this forest will be presented in the future, as well as useful data that serve for making new decisions on programs and public policies for the management, conservation and restoration of the mangrove forest in the future.

Because, by conserving and/or increasing the mangrove areas that have been lost, it would benefit the social sector, providing protection against the impact of natural phenomena, as well as generating greater economic income for the local and regional population by increasing the populations of commercial fishing species, it would also promote sustainable reforestation and restoration work activities. It also benefits the environment because the mangrove forest provides shelter, food, space for the reproduction of flora and fauna that coexist in the landscape, and absorbs CO_2, which will contribute to climate change mitigation.

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APPENDIX

Diagnosis of information on the factors causing deforestation and degradation in the mangrove forest.

The survey aims to investigate the causes of the processes of deforestation and degradation of the mangrove forest. This study focuses on the perception of experts on the subject and the people wholive in this area, on the information of the mangrove cover, in order to evaluate the main causes that have led to these processes.

General data
Nombre:____
Profesión:____
Ocupación:____
Dependencia:____
Correo electrónico:____
Teléfono:____
Sector the respondent represents:
Government_______**Private sector**_______**Non-Governmental Organization (NGOs)**_________
Academic/Research sector________**Fisheries/Cooperativist**________**Other**_______
Indicate: _____________________

1. Do you know why mangroves are important?	**Null**	**Slight**	**Moderate**	**High**
Filters the water keeping it clean and absorbing heavy metals				
Protects against floods, hurricanes, tropical storms and other natural phenomena.				
Control soil erosion				
Forests absorb the most atmospheric carbon dioxide.				
Fish, mollusks, shrimp and other crustaceans are raised in the mangrove forest				
They are a refuge for fauna (birds, reptiles and insects).				
Helps regulate the climate				
Provides optimal conditions for the establishment of aquaculture farms.				
The soil types around the mangroves provide optimal conditions for agricultural establishment.				
The soil types around the mangroves provide optimal conditions for livestock establishment.				
They provide economic income from fishing around the mangroves.				
Provide economic income with respect to tourism and ecotourism (due to the scenic richness of this ecosystem).				
These forests are of research interest				
2. Have you obtained any benefit from mangrove forests?	**Null**	**Slight**	**Moderate**	**High**
Lumber for roofing or fencing				
Medicinal products				
Wood for charcoal making				

Firewood				
Fish or other animals for consumption or sale				
3. Have you done any activities in or around mangrove forests?	**Null**	**Slight**	**Moderate**	**High**
Fishing				
Hunting				
Bird watching				
Boat ride				
Cattle raising				
Planting of a seedling				
Ecotourism				
Tourism				
Reforestation				
4. Do you believe that the mangrove forest area has decreased?	**Yes**	**No (Go to question 9)**		
5. What do you think will cause the mangrove forest area to decrease due to anthropogenic factors?	**Null**	**Slight**	**Moderate**	**High**
Expansion of infrastructure (canals, roads, highways, hotels, houses)				
Agricultural activity around mangroves				
Livestock activity around mangroves				
Beekeeping				
Free fishing				
Mining				
Aquaculture				
Ecotourism				
Tourism				
6. What do you think will cause the mangrove forest area to decrease with respect to environmental factors?	**Null**	**Slight**	**Moderate**	**High**
Hurricanes				
Tropical storms				
Tsunamis				
Sea level rise				
Contamination				
High temperatures				
7. What do you think will cause the mangrove forest area to decrease with respect to economic factors?	**Null**	**Slight**	**Moderate**	**High**
Growth of the local market (fish, crustaceans and mollusks)				
Regional marketing (fish, crustaceans and mollusks)				
Agricultural market growth				
Livestock market growth				
8. What do you think will be the cause of the mangrove forest area decrease with respect to social factors?	**Null**	**Slight**	**Moderate**	**High**
Lack of knowledge about the importance of the mangrove forest				

Lack of public programs and policies for the conservation of mangrove forests				
Lack of interest of the near-shore population in the importance of mangrove conservation.				
9. Do you believe that the mangrove forest area has been increasing?	**Yes**	**No (Go to question 11)**		
10. What do you think has been the cause of the increase in mangrove forest area?	**Null**	**Slight**	**Moderate**	**High**
Natural growth (natural recovery)				
Reforestation programs				
Mangrove protection (programs and public policies)				
11. Do you believe that mangrove areas have been disturbed over the years?	**Yes**	**No (Go to question 13)**		
12. What do you think has been the cause of the disturbance of the mangrove forest?	**Null**	**Slight**	**Moderate**	**High**
Environmental conditions (hurricanes, tropical storms, tsunamis, sea level rise)				
Economic growth				
Quality of life of the population (taking advantage of the benefits that mangroves provide).				
13. What do you think the mangrove forest will look like in 2030?	**Null**	**Slight**	**Moderate**	**High**
Mangrove cover will decrease				
The mangrove area will increase				
Disturbed mangrove area will increase				
14. What do you think will cause the mangrove forest area to increase in the future?	**Null**	**Slight**	**Moderate**	**High**
Naturally (regeneration)				
Improved public policies for conservation and management				
Reforestation programs				