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A Practical Index to Estimate Mangrove Conservation Status: The Forests from La Paz Bay, Mexico as a Case Study

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Abstract: Mangrove cover has declined significantly in recent years in tropical and subtropical areas around the world. Under this scenario, it is necessary to elaborate and implement tools that allow us to make estimations on their conservation status and improve their protection and support decision-making. This study developed an index using qualitative and quantitative data. The criterions used in the index were: (1) Remnant Vegetation Index, (2) Delphi Method Survey, and (3) Rapid Assessment Questionnaire. In turn, the weights of the criterions were defined using the analytical hierarchy process (AHP). Once the values of each criterion were obtained, the index was applied to 17 mangrove communities located in La Paz Bay, Mexico. Finally, according to their score, they were classified based on the IUCN Red List of Ecosystems. The results show that five communities were ranked in the category Minor Concern, eight in Little Threatened, one in Vulnerable, one in Endangered, and two were classified as Deficiency of Data. These results are slightly different from other studies in the region and validate this index as a proper method. Therefore, it could be applied to other sites, especially in areas with little information and/or scarce monetary resources.

Keywords: AHP; Delphi Method; GIS; MCDA; Sustainable Development; Wetlands

1. Introduction

1.1. Theoretical Background

Mangroves are recognized worldwide due to various resources and ecosystem services (ES) they provide [1,2]. Some of these ES are provision services (food, timber, medicines, etc.), regulation and maintenance services (protection against hurricanes, erosion control, CO_2 capture, etc.), and cultural services (aesthetic, symbolic, religious, etc.) [3,4]. The presence of coastal wetlands such as mangroves helps contribute to human wellbeing [5,6]. However, mangroves are one of the most threatened coastal ecosystems due to changes in environmental factors and impacts induced by human activities [7]. They are particularly vulnerable to degradation as a result of deforestation, aquaculture, agriculture, tourism, urbanization, and pollution from different sources [8]. Other factors, such as sediment dynamics, exotic species, and alteration of the hydrodynamics, also result in severe mangrove deterioration and habitat loss [9].

According to FAO data, about 3.6 million hectares of mangroves were lost in the 1980–2005 period, approximately 20% of the global mangrove cover [10]. Also, it is estimated that mangrove forests worldwide are disappearing between one to two percent each year, at a higher rate than rainforests or coral reefs [11]. Likewise, it is recognized that only 6.9% of the world's mangroves are in the category of a protected area network [12]. In México, the National Commission for the Use and Conservation of Biodiversity (CONABIO) through the Mexican Mangrove Monitoring System (SMMM) began a full examination of the mangroves in this country. The SMMM observed that in 1970–1980, Mexico presented a cover of 856,405 hectares but by 2015 the number of hectares of mangroves decreased to 775,555 [13]. This loss of mangroves has been observed in urban areas and in zones with a tourist-oriented vision. A well-known example is the destruction of "Tajamar" mangrove, in Cancun city, in 2016 [14].

Another example is the case of mangroves located in La Paz city. The capital of Baja California Sur state, has caused a remarkable anthropic pressure to their mangroves due to the growing urbanization [15]. Also, it is expected that tourism will increase in this city. This is evidenced in the list "52 Places to Go in 2020" of The New York Times, where La Paz was the only Mexican city nominated [16]. In this context, different forums, such as the "I Workshop on Mangroves of the Baja California Peninsula" (2005) and the "I Workshop of RAMSAR Sites of Baja California Sur" (2009) have highlighted the need to know the state of mangroves in La Paz bay. Therefore, the goal of this work was to develop an integrative index to evaluate the conservation status of mangroves in this region.

1.2. Study Area

La Paz Bay is in the southwest of the Gulf of California, at the southern portion of the Baja California Peninsula, in Mexico (Figure 1). This bay has diverse biotic and abiotic characteristics that made it a remarkable site with diverse ecosystems, such as beaches, dunes, seagrass beds, rocky reefs, and mangroves [17]. Its coastal zone harbors 17 mangrove communities, 16 of them within the proximity of La Paz city, and one more at the Espíritu Santo Archipelago. These mangroves are within protected areas such as the Espíritu Santo Archipelago National Park, the Balandra Flora and Fauna Protection Area, and the Islands of the Gulf of California Flora and Fauna Protection Area. They are also under the category of international protection, such as the Ramsar Sites "Humedales Mogote-Ensenada de La Paz" (Ramsar site no. 1816) and "Balandra" (Ramsar site no. 1767).

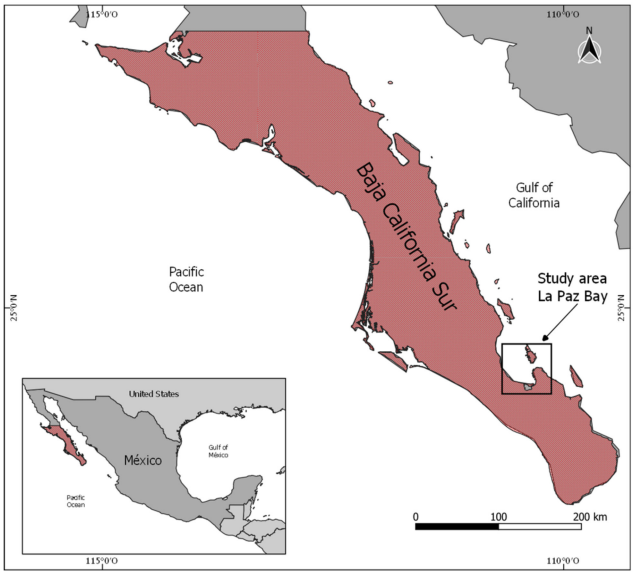

Figure 1. Location of La Paz Bay in the southern end of the Peninsula of Baja California, Mexico.

The 14 communities belonging to the Ramsar site No. 1816 are: Centenario-Chametla, Comitán, El Conchalito, El Mogote, Enfermería, Eréndira, Estero Bahía Falsa, Estero El Gato, La Paz-Aeropuerto, Palmira, Playa Pichilingue-Brujas, Unidad Pichilingue UABCS, Salinas de Pichilingue, and Zacatecas. Two of these remaining communities belonging to Ramsar site no. 1767 are Balandra and El Merito. Finally, the mangrove Espíritu Santo Archipelago is located within another protected area, it is in the national park category and its name is homonymous to that community (Figure 2).

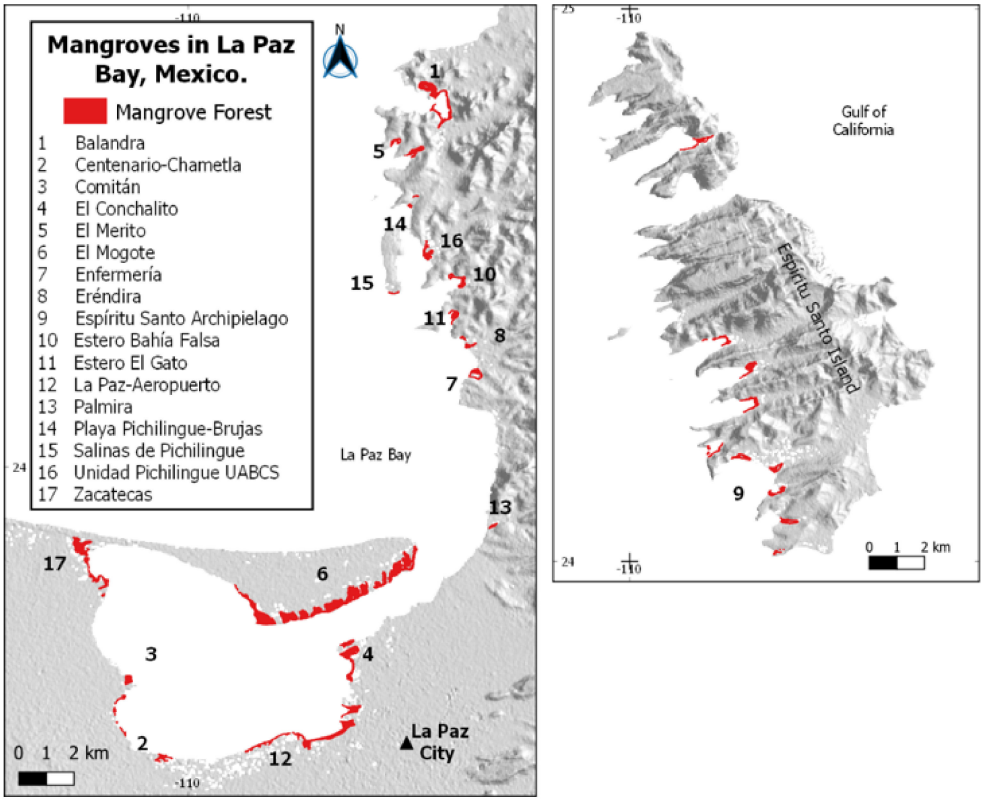

Figure 2. Location of mangroves placed in La Paz Bay, Mexico.

2. Materials and Methods

2.1. Study Design

The development and implementation of the Mangrove Conservation Status Index (MCSI) consisted of five phases carried out between January and September 2019. First, the remnant vegetation index (RVI), Delphi method survey (DMS), and the rapid assessment questionnaire (RAQ) were conducted at the 17 mangrove areas during January–February 2019, followed by the use of the analytical hierarchy process (AHP) to estimate the weights of each one of these indicators. We conducted a spatial analysis on open-source GIS software QGIS (version 3.4.4) to calculate the RVI, designed a questionnaire for the RAQ, and applied surveys to local mangrove experts for the DMS. Finally, we estimated the Mangrove Conservation Status Index for all the mangroves.

2.2. Index Development and AHP

For the construction of the MCSI, three components were selected, as these are widely used in various environmental analyses (RVI, DMS, and RAQ). For example, several studies have carried out comparisons between mangrove cover between different years, globally and nationally and locally. Also, the application of the Delphi method in environmental modeling is considered as a useful tool, with various studies focused on mangroves. Finally, the rapid assessment tool has also been used

in forest and wetland analysis. Once the index components were selected, the following formula was generated:

$$\textbf{MCSI} = (\text{RVI})W1 + (\text{DMS})W2 + (\text{RAQ})W3.$$

The weights of each component were determined using the analytical hierarchy process (AHP) method developed by Thomas L. Saaty (see Appendix A). For this, paired combinations were made between the three components using a pairwise comparison matrix (Table 1). For example, since the RVI is a quantitative value that reflects the loss or gain of cover in a given period, it was considered of greater relevance than the RAQ and DMS components. In the same way, among these last components, the DMS was considered of greater importance than RAQ. DMS is the result of the opinion of several experts (which includes years of experience) in comparison to RAQ, which takes information from a single field visit.

Table 1. Pairwise comparison matrix (PCM).

Criteria	Sub-Criteria	Number of Comparisons			Total	Weight
		1	2	3		
MCSI	(1) Remnant Vegetation Index		5	5	10	0.62
	(2) Delphi Method Survey.	1		3	4	0.25
	(3) Rapid Assessment Questionnaire.	1	1		2	0.13

2.3. Remaining Vegetation Index (RVI)

The value of RVI of each mangrove community was calculated by considering the vegetation cover obtained in 2018 as the present vegetation area (PVA), divided by the original vegetation area (OVA), which corresponded to the data of the year of 1973. The result was multiplied by 100 to obtain a comparable value on a scale of 0/100. This index was used for the first time in a case study in Colombia [18] following this formula:

$$\textbf{RVI} = [(\text{PVA})/(\text{OVA})] \times 100.$$

We obtained the vegetation area from scanned aerial photographs and Landsat satellite images. We consulted CONABIO's database. We used the oldest image available from the sources mentioned above for the calculation of the RVI for each mangrove community. In this case, we obtained an aerial photograph from 1974 that captured mangroves, except those at Espíritu Santo Archipelago, in La Paz bay at the Autonomous University of Baja California Sur library's archive. We downloaded Sentinel images (10 m, 20 m, and 60 m, avoiding cloud interference) for May 2018 from the Earth Explorer platform (USGS) to calculate present vegetation cover for the calculation of the RVI.

To digitalize the aerial photographs, we scanned them with the highest available resolution (10,200 × 14,028 pixels). We georeferenced images using geomorphological land references by the control point method. Subsequently, we extracted the sections corresponding to mangroves on QGIS and obtained pixels (1 m × 1 m) by a resampling process. The resampling process did not allow for a higher pixel resolution; nevertheless, it provided better contrast between neighboring pixels. Therefore, observations allowed the precise definition of mangrove areas (Figure 3).

Together, the field data collection and the georeferenced aerial photographs allowed the confirmation of the presence of mangroves and the obtention of the polygons containing mangroves by the use of the on-screen scanning facility in the QGIS software. We transformed the satellite image from geographic coordinates to metrics. For optimal use, we created a composite of bands 4, 5, 3, and panchromatic (Band 8) to increase image resolution and facilitate vegetation recognition [19]. The generation of the base project in the QGIS platform integrated the resulting images in raster format. Once the properties of the images (pixel size, georeference) were validated, we calculated the mangrove cover for each of the 17 sites. We obtained 16 mangrove polygons for 1974 and 17 for 2018 using

the manual digitizing technique which has been used by different authors [20–23] and estimated the vegetation cover area. We used the resulting areas to calculate the RVI.

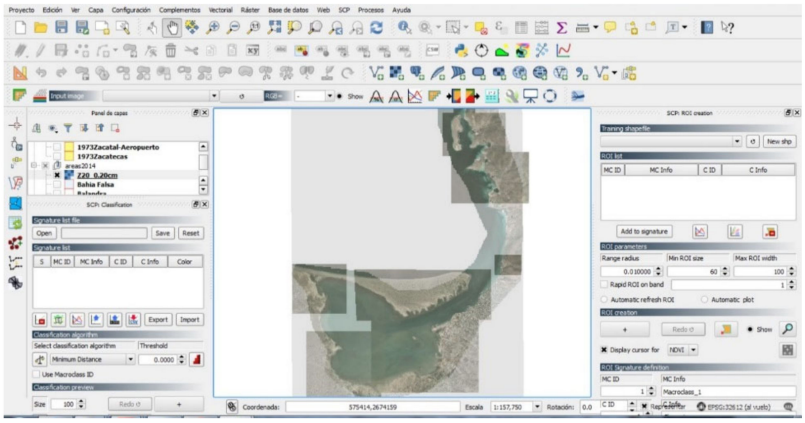

Figure 3. Treatment of spatial images in the QGIS software.

2.4. Delphi Method Survey

We applied interviews with regional mangrove experts following the Delphi method, which is a structured way to obtain information and knowledge on a particular topic [24]. This method provides both qualitative and quantitative data (see Appendix B), and it can be adapted for rapid assessments, such as the one implemented during this study [25]. We contacted a total of ten people, but only seven answered the survey. Of these, four were researchers, two worked for government agencies, and one collaborated with non-government organizations. We conducted interviews in person or remotely via electronic media such as Skype or video conference. The interview consisted mostly of open questions, as well as closed questions or fixed-alternatives. Interviewees answered the open question freely with no limit on time. The fixed-alternative questions were formulated to be answered in a scalar way using the Likert measurement tool (Table 2), which consists of obtaining a degree of conformity determined by a range of values. Table 3 shows the main question used in the survey.

Table 2. Remaining Vegetation Index obtained for each mangrove community.

Mangrove Community	Original Vegetation Area (m^2)	Present Vegetation Area (m^2)	Remaining Vegetation Index (Scores)
Balandra	266,044.01	268,577.08	**100.95**
Centenario-Chametla	54,213.98	53,657.47	98.97
Comitán	43,982.36	42,448.27	96.51
El Conchalito	217,785.87	192,957.92	88.59
El Merito	81,397.13	81,373.77	99.97
El Mogote	1,247,826.06	1,254,511.24	**100.53**
Enfermería	56,953.15	37,968.09	66.66
Eréndira	23,627.20	23,969.85	**101.45**
Espíritu Santo Archipelago	-	523,773. 69	N/A
Estero Bahía Falsa	47,744.44	44,573.39	93.35
Estero El Gato	47,916.84	45,429.86	94.80
La Paz-Aeropuerto	160,633.55	360,491.36	**224.41**
Palmira	14,172.06	12,154.07	85.76
Playa Pichilingue-Brujas	11,210.63	3,025.02	26.98
Salinas de Pichilingue	-	2,971.47	N/A
Unidad Pichilingue UABCS	63,284.70	50,329.61	79.52
Zacatecas	227,058.89	259,119.05	**114.11**

Note: Bold scores represent increases on mangrove cover.

Table 3. Key question applied to experts in the Delphi Method Survey component.

Based on your experience, what is the conservation status of the mangroves of the bay of La Paz?		
Mangrove Communities	**Conservation Status**	**I Don't know.**
Balandra	Bad 1 2 3 4 5 Good	

2.5. Rapid Assessment Questionnaire

The rapid evaluation is a reliable and timely estimation method, which allows an approximation of the magnitude and characteristics of a problem. It marks the line to define needs or tasks to consider during a subsequent evaluation [26]. This type of assessment provides complementary information to other sources, in a simple, fast, and flexible way. In the case of the mangroves of La Paz Bay, we visited 17 sites, which were selected according to the management plans of the protected area (Balandra) and Ramsar site (Humedales Mogote-Ensenada de La Paz No. 1816). To evaluate each of the mentioned mangroves, we created a rapid assessment questionnaire (*RAQ*) based on different surveys developed by academics and decision-makers from the region. The *RAQ* considered specific environmental indicators, divided thematically (water, air, soil, flora, fauna, and waste), and used qualitative indicators to assess impacts observed at each mangrove site during the field visits. The values of the *RAQ* ran from 0 to 1; the closer the value to 1, the more impacted the site was. We recorded our observations at the site, and photographic evidence is available from the authors upon request (see Appendix C).

2.6. Application of the Integrative Mangrove Conservation Status Index

We calculated the *MCSI* using the scores of each one of the components of the index, RVI, RAQ, and DMS, and following the formula:

$$\textbf{MCSI} = (\text{RVI})(0.62) + (\text{RAQ})(0.25) + (\text{DMS})(0.13).$$

We classified mangrove sites depending on their MCSI score following an adapted classification of the IUCN Red List of Ecosystems (see Appendix D). This scale considers eight categories of risk for the earth's ecosystem (Figure 4). Three of them contemplate quantitative thresholds: critically endangered (CR), endangered (EN), and vulnerable (VU)—together, the IUCN describes these ecosystems as threatened. There are several qualitative categories to include: (1) ecosystems that fail to meet the quantitative criteria for the threatened ecosystem categories (NT, near threatened); (2) ecosystems that unambiguously meet none of the quantitative criteria (LC, least concern); (3) ecosystems with poor data (DD, data deficient); and (4) ecosystems that have not been assessed (NE, not evaluated). An additional category (CO, collapse) is assigned to ecosystems that have collapsed throughout their distribution, the analogue of the extinct (EX) category for species [27].

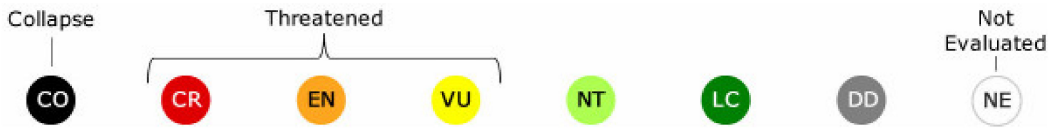

Figure 4. Categories of the IUCN Red List of Ecosystems. Source: IUCN, 2019.

3. Results

To calculate the proposed MCSI, we first estimated each of the components for the 17 mangroves from La Paz Bay. We summarize our findings in the following sections.

3.1. Spatial Analysis and Remaining Vegetation Index (RVI)

According to the RVI analysis, five communities presented an increase in mangrove cover (RVI > 100), ten showed losses of mangrove forest (RVI < 100), and two could not be analyzed because

we were not able to obtain an original vegetation area. Playa Pichilingue-Brujas experienced the most significant losses of mangrove vegetation, and only 26.98% of the initial cover remained. Enfermería also presented a significant decrease in mangrove cover (44.44%).

3.2. Delphi Method Survey

We sent a total of 10 surveys to regional mangrove experts; however, just seven people replied. We interviewed them to complement their answers to the surveys (available from the authors upon request). We calculated the median for the score assigned by the experts to each one of the mangrove areas. Only two mangrove communities presented median scores of five, El Merito and Espíritu Santo Archipelago, which presents the best conservation status according to expert opinions (Table 4). Five mangrove areas scored four points for an acceptable conservation level. Moreover the mangroves that scored less than three, meant that they present a major deterioration.

Table 4. Values obtained from the Delphi Method Survey applied to experts.

Mangrove Community	Expert Opinion 1	Expert Opinion 2	Expert Opinion 3	Expert Opinion 4	Expert Opinion 5	Expert Opinion 6	Expert Opinion 7	Median
Balandra	4	3	4	4	5	4	4	4
Centenario-Chametla	2	2	3	2	4	2	2	2
Comitán	2	4	4	4	3	3	4	4
El Conchalito	3	2	3	3	4	2	3	3
El Merito	5	-	5	5	4	5	5	5
El Mogote	3	3	4	4	4	4	4	4
Enfermería	1	-	2	2	3	3	2	2
Eréndira	2	2	2	2	1	4	2	2
Espíritu Santo Archipelago	5	-	5	5	3	-	5	5
Estero Bahía Falsa	3	3	3	2	3	3	3	3
Estero El Gato	4	3	3	4	-	3	4	3
La Paz- Aeropuerto	4	3	4	3	5	4	4	4
Palmira	4	2	2	2	3	2	2	2
Playa Pichilingue-Brujas	2	2	1	1	4	2	2	2
Salinas de Pichilingue	-	-	3	3	-	-	-	-
Unidad Pichilingue UABCS	2	3	3	3	4	3	3	3
Zacatecas	4	-	5	4	4	4	5	4

3.3. Rapid Assessment Questionnaire

The mangroves in La Paz bay presented a varied rank of values for the RAQ. The La Paz-Aeropuerto, Palmira, and Playa Pichilingue–Brujas mangrove communities were the most impacted sites, with RAQ scores between 0.80 and 0.90. Seven mangroves showed medium levels of impact, with scores ranging between 0.50 and 0.70, and another seven sites presented fewer effects, with RAQ values from 0.26 to 0.49 (Table 5).

Table 5. Values obtained from the Rapid Assessment Questionnaire applied in field visits.

Mangrove Community	Rapid Assessment Questionnaires
Balandra	0.4944
Centenario-Chametla	0.6542
Comitán	0.2662
El Conchalito	0.5680
El Merito	0.3184
El Mogote	0.4486
Enfermería	0.5896
Eréndira	0.7260
Espíritu Santo Archipelago	0.2662
Estero Bahía Falsa	0.6382
Estero El Gato	0.5604
La Paz-Aeropuerto	0.8178
Palmira	0.8858
Playa Pichilingue-Brujas	0.8960
Salinas de Pichilingue	0.2884
Unidad Pichilingue UABCS	0.6504
Zacatecas	0.4026

3.4. Application of the Index

We multiplied the scores of the RVI, DMS, and RAQ, as described to calculate the MCSI. The El Merito mangrove community presented the highest MCSI of all the sites (95.54), followed by Balandra, Comitán, El Mogote, Estero El Gato, and Zacatecas, which scored values over 80; therefore, these five communities are of "least concern" in accordance with the IUCN Red List of Ecosystems. The MCSI values of another eight mangroves placed them as "near threatened". Otherwise, Enfermeria was classified as "vulnerable", with an MCSI score of 59.22, and Playa Pichilingue-Brujas was classified as "endangered" (MCSI score of 30.01), these last two mangroves were the worst evaluated. Lastly, two mangroves, Salinas de Pichilingue and Espíritu Santo Archipelago, lacked initial information on mangrove cover; therefore, the MCSI resulted in "data deficient" (Table 6).

Table 6. MCSI values for each mangrove community.

Mangrove Community	RVI Score	DM Score	RA Score	MCSI	IUCN Red List of Ecosystems
Balandra	57	23.2	7.0784	87.2784	Least Concern (LC)
Centenario-Chametla	57	11.6	4.8412	73.4412	Near Threatened (NT)
Comitán	57	17.4	10.2732	84.6732	Least Concern (LC)
Espíritu Santo Archipelago	-	29	10.2732	-	Data Deficient (DD)
El Conchalito	54.6231	17.4	6.048	78.0711	Near Threatened (NT)
El Merito	57	29	9.5424	95.5424	Least Concern (LC)
El Mogote	57	23.2	7.7196	87.9196	Least Concern (LC)
Enfermería	41.8836	11.6	5.7456	59.2292	Vulnerable (VU)
Eréndira	57	11.6	3.836	72.436	Near Threatened (NT)
Estero Bahía Falsa	57	17.4	5.0652	79.4652	Near Threatened (NT)
Estero El Gato	57	17.4	6.1544	80.5544	Near Threatened (NT)
La Paz-Aeropuerto	57	17.4	2.5508	76.9508	Near Threatened (NT)
Palmira	53.8593	11.6	1.5988	67.0581	Near Threatened (NT)
Playa Pichilingue-Brujas	16.9575	11.6	1.456	30.0135	Endangered (EN)
Salinas de Pichilingue	-	-	9.9624	-	Data Deficient (DD)
Pichilingue UABCS	45.5316	17.4	4.8944	67.826	Near Threatened (NT)
Zacatecas	57	23.2	8.3636	88.5636	Least Concern (LC)

4. Discussion

Various scientists have developed evaluation indices that can estimate the conservation status-health of mangroves [28–30]. However, many times the application of some indexes requires financial resources, specialized equipment, and experts, which are not always available. This occurs mainly in developing countries and at the same time in these sites information is required in an expedited manner for decision making. Therefore, we believe that the MCSI could help in the aforementioned scenario, which is so common in various countries in Latin America, Africa, and Asia.

Although this index is easy to apply and requires few financial resources, it is based on a combination of quantitative and qualitative data, which gives adequate support to the decisions generated from the results obtained. It combines mangrove cover (remnant vegetation index) with scientific experts' opinions (Delphi method survey), and perceived conservation status obtained during field visits (rapid assessment questionnaire) to classify mangroves in accordance with the IUCN Red List of Ecosystems. For that purpose, the MCSI used the analytical hierarchy process to define the weight of various indicators following a multicriteria method, as suggested by other authors [31].

Besides this, we can consider that the main finding of the construction and application of the MCSI index was that in general terms the mangrove communities located in the Bay of La Paz have an acceptable state of conservation. On the other hand, these results also indicate that despite being in the same area, mangroves could have very different conservation status.

The MCSI uses mangrove cover as a core indicator, which is also applied by the Mexican Mangrove Monitoring System (SMMM), but also is complemented by experts' opinions and rapid assessments at the mangrove communities. Still, different authors consider that cover is not sufficient to estimate the conservation [32,33], since it does not take into consideration other impacts on the ecosystems or the integrity of the ecological services they provided.

We complemented mangrove cover with the remaining vegetation index (RVI) because it estimates changes on vegetation cover in a specific period. The RVI determined an increase between 1974 and 2018 in the cover area of five mangrove communities in La Paz bay: Balandra, El Mogote, Eréndira, La Paz-Aeropuerto, and Zacatecas; however, the rest of the mangrove areas experienced a decrease in mangrove cover (Table 2). The most affected mangroves, Playa Pichilingue-Brujas and Enfermería, experimented significant human-induced impacts during the last decades, mainly the reduction of their connection to the sea by the construction of roads [34]. Mangroves present in La Paz bay facilitated the use of aerial and satellite imagery for the estimation of the RVI because they are adjacent to desertic areas, which showed high contrast with mangrove species. However, different authors consider that

the cover estimations by this method are limited when mangroves are close to other types of forest or wetlands, and additional corrections are necessary [35,36].

The integration of data obtained by different methods has proven difficult [37]; therefore, this study used mixed methods to integrate qualitative and quantitative data, and most importantly, changes in mangrove cover with scientific expert's opinions. This last indicator is essential when the number of experts is limited, but their knowledge in the region is plenty. The information obtained by the DMS contrasted in some cases with the cover estimated by the RVI. In such cases, the scientific experts considered that some mangroves, e.g., El Mogote and Erendira, were in a poor state of conservation (Table 4). Still, those sites presented an increase in cover between 1974 and 2018, according to the RVI (Table 3). For those cases, the RAQ demonstrated the presence of some visible impacts, such as gray water inputs and modification of water circulation, which may be limiting the ecosystem services that mangroves should provide but increased their cover. Some of these impacts change over time; for example, solid waste was observed previously at Comitán but not registered during the RAQ thanks to a cleaning campaign that took place the day before the field visit. Therefore, the MCIS approach highlights the need to integrate expert opinions and field data.

The use of the MCSI scores to classify mangrove communities according to the IUCN Red List of Ecosystems is a novel approach. The analysis for 17 mangroves in La Paz bay resulted in five sites in the category of least concern (LC), and eight considered as near threatened (NT). On the other hand, one of them, the Enfermería mangrove area, is vulnerable (VU), and the Pichilingue-Brujas mangrove is endangered (EN). Finally, two mangroves, Salinas de Pichilingue and Espiritu Santo Archipelago, were classified as data deficient (DD). However, according to partial results, it is currently estimated that Salinas de Pichilingue and Espiritu Santo Archipelago have a good state of conservation, especially in the last case (Figure 5).

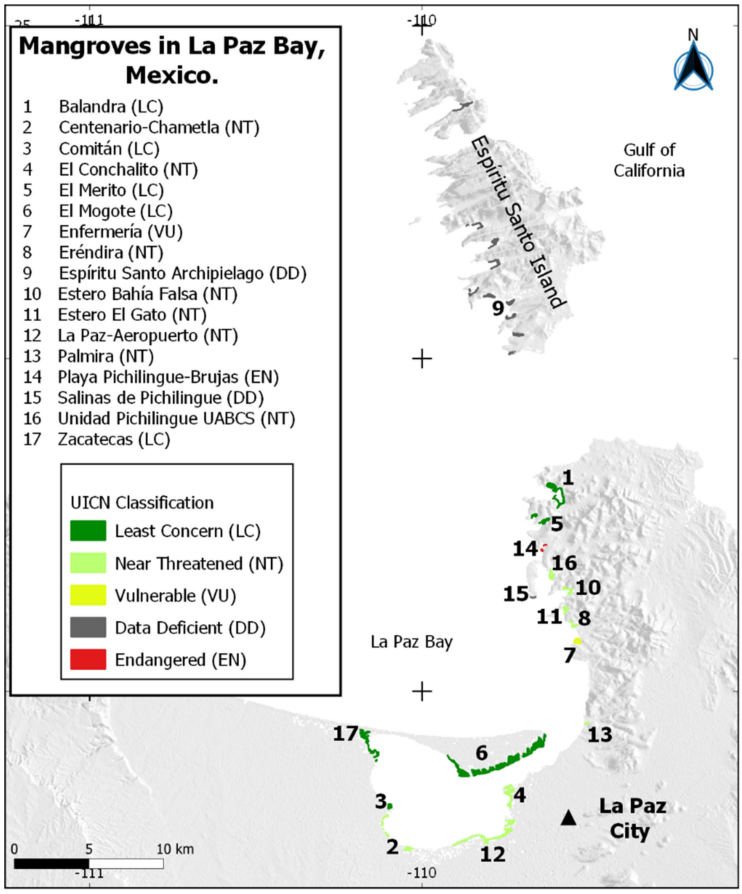

Figure 5. Classification of La Paz Bay mangroves, according to their conservation status.

Accordingly, the MCSI was adequate for the case study and helped to define conservation priorities for the mangroves in the region. The integrative nature of the index allowed for the identification of factors that negatively affect the conservation status of the mangroves, e.g., losses of vegetation, changes in water circulation, or solid waste presence. Then, it can be instrumental for the effective implementation of ecological restoration activities undertaken in areas [38,39]. The application of the MCSI by managers in this region may help to revert the condition of those mangrove areas that have suffered significant deterioration or to address other adverse factors threatening these ecosystems [40]. However, it is estimated that the urbanization caused by the tourism industry will be the most threatening factor for the conservation of mangroves in La Paz Bay, especially if it does not consider the applicable environmental regulations. Although several of the mangrove communities are small, due to their ecosystem services, these must be conserved [41].

Finally, it is concluded that the results on conservation status are more robust than those that include only spatial data and, by their integration into the IUCN Red List of Ecosystems, allow a direct comparison not only with other mangroves but also with different aquatic and terrestrial environments around the world. We recommend the application of the MCSI not only as a decision-making tool but also as an exploratory study; nonetheless, it is advisable to conduct follow up monitoring of quantitative ecological indicators to strengthen and provide feedback to update the MCSI.

5. Conclusions

The results of the present work constitute the first innovative use of the categorization of the Red List of Ecosystems by the IUCN for the mangroves communities. The MCSI integrates not only reliable quantitative indicators but also qualitative indicators to provide a more accurate conservation status for the mangrove communities; however, it is limited by the availability of data for some areas of interest. The multidisciplinary approach of the MCSI allows for its application at data deficient mangrove communities for an initial evaluation and guides future research efforts. The proposed MCSI index is a reliable tool for the management and conservation of mangrove communities; nonetheless, it could be improved as new methods to collect substantial data for additional indicators become available.

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Appendix A

The analytical hierarchy process (AHP) proposed by Thomas L. Saaty (1980) is a method to express the relative importance or dominance of individual element(s) over an assessment, such as criteria or characteristics useful, for example, for decision-making [42]. This technique organizes the evaluation elements into a hierarchy level, assigning numerical values, which gives mathematical support to the organization. The AHP uses pairwise comparison or paired ranking to compare the various elements of the analysis. This comparison is based on a numerical qualification, considering a prime number subjacent scale from 1 to 9 (Saaty scale). Data are entered into a squared matrix to give qualifications; therefore, the level of importance (Table A1).

Table A1. Saaty scale used in paired ranking.

Scale Values	Values Definition	Definition
1	Equal importance	An equal level of importance for both evaluation elements that are being compared
3	Somewhat more or weak importance	One element is slightly more important or relevant than the other
5	Much more or essential importance	One element is more important or essential than the other.
7	Very much or demonstrated importance	One element is much more important or relevant than the other
9	Extreme or absolute importance	One element is definitely more important than the other

Appendix B

The Delphi survey method is a research technique proposed by The RAND Corporation in the 1950s (Table A2). It is a group communication process [43], with reference to a collection of answers in order to obtain and improve information resulting from opinions made by experts in a particular theme [44]. This methodology is based on the application of a series of questions, all of which are submitted once or several times if necessary, with the objective to achieve feedback and enrich opinions [45]. The origin and number of these may come from either the academic sector, industrial, governmental, or civil society organizations. It should be mentioned that the expert selection must be done considering their previous experience and current work on the subject. Using these opinions, this method seeks to develop a previously non-existent or dispersed knowledge useful in the decision-making process in government, science, and industry areas [46].

Table A2. Delphi method process description (based on Mukherjee et al. 2014).

1. FIRST ROUND
2. ⬇
3. PREPARE QUESTIONNAIRE
4. ⬇
5. SELECT EXPERTS IN ORDER TO OBTAIN THEIR OPINION
6. ⬇
7. INVITE THEM TO PARTICIPATE ON DELPHI
8. ⬇
9. COLLECT ANSWERS, ANALYSE, AND PROVIDE FEEDBACK
10. ⬇
11. SECOND ROUND
12. ⬇
13. PREPARE AND SEND QUESTIONNAIRE
14. ⬇
15. COLLECT ANSWERS, ANALYSE, AND PROVIDE FEEDBACK
16. ⬇
17. REPEAT ROUNDS UNTIL CONSENSUS IS REACHED

Appendix C

Rapid assessment or rapid appraisal (RA) is a quick and accurate estimation method to collect in situ information [47]. This technique allows for an immediate approximation to the magnitude and characteristics of a particular situation. It is an approach for developing a preliminary, qualitative understanding [48]. RA marks the line to define needs or tasks to be carried out in posterior assessments (Figure A1); it provides supplemental information to other sources, in a simple, fast, and flexible way [49]. The RA method uses various tools to collect data; for example, the recording of observations in logbooks or through questionnaires, participatory surveys. All these methods have the purpose of giving fast and reliable results. RA's fundamental advantage is that it is itself "a phase or stage in a research process"; therefore, it allows for scientific rigor [50].

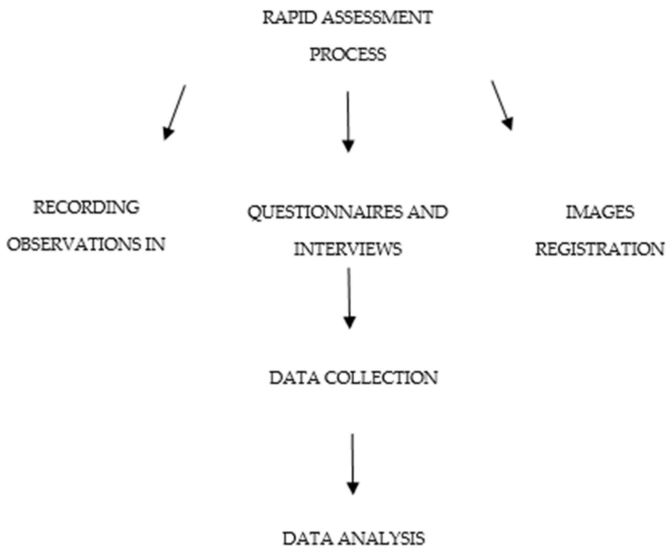

Figure A1. Rapid assessment process and elements.

Appendix D

The IUCN Red List of Ecosystems Categories and Criteria is a global standard for how we assess the status of ecosystems, applicable at local, national, regional, and global levels [51,52]. In this work, we artificially established the values to classify mangroves in each of the categories. Each criterion used for each category is described after the definitions mentioned below (Table A3).

Table A3. List of scores for each category of the MCSI Index. (Based on Keith et al., 2015).

IUCN Red List of Ecosystems	Score
Collapsed (CO)	0
Critically endangered (CR)	01–20
Endangered (EN)	21–40
Vulnerable (VU)	41–60
Near Threatened (NT)	61–80
Least Concern (LC)	81–100
Data Deficient (DD)	N/A
Not Evaluated (NE)	N/A

- Collapsed (CO)

"An ecosystem is Collapsed when it is virtually certain that its defining biotic or abiotic features are lost from all occurrences, and the characteristic native biota are no longer sustained. Collapse may occur when most of the diagnostic components of the characteristic native biota are lost from the system, or when functional components (biota that performs key roles in ecosystem organization) are greatly reduced in abundance and lose the ability to recruit" (IUCN, 2019). In this category, the entire vegetation cover of the mangrove community has been destroyed.

- Critically Endangered (CR)

"An ecosystem is Critically Endangered when the best available evidence indicates that it meets any of the criteria A to E for Critically Endangered. It is therefore considered to be at an extremely high risk of collapse" (IUCN, 2019). In this category, the index score obtained by the mangrove community is less than 20 but higher than zero.

- Endangered (EN)

"An ecosystem is Endangered when the best available evidence indicates that it meets any of the criteria A to E for Endangered. It is therefore considered to be at a very high risk of collapse" (IUCN, 2019). In this category, the index score obtained by the mangrove community is less than 40 but higher than 20.

- Vulnerable (VU)

"An ecosystem is Vulnerable when the best available evidence indicates that it meets any of the criteria A to E for Vulnerable. It is therefore considered to be at a high risk of collapse" (IUCN, 2019). In this category, the index score obtained by the mangrove community is less than 60 but higher than 40.

- Near Threatened (NT)

"An ecosystem is Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future" (IUCN, 2019). In this category, the index score obtained by the mangrove community is less than 80 but higher than 60.

- Least Concern (LC)

"An ecosystem is Least Concern when it has been evaluated against the criteria and does not qualify for Critically Endangered, Endangered, Vulnerable or Near Threatened. Widely distributed and relatively undegraded ecosystems are included in this category" (IUCN, 2019). In this category, the index score obtained by the mangrove community is equal to or less than 100 but higher than 80.

- Data Deficient (DD)

"An ecosystem is Data Deficient when there is inadequate information to make a direct, or indirect, assessment of its risk of collapse based on decline in distribution, disruption of ecological function or degradation of the physical environment. Data Deficient is not a category of threat, and does not imply any level of collapse risk" (IUCN, 2019). In this category, some of the information considered for the application of the index in a particular mangrove community was not available.

- Not Evaluated (NE)

"An ecosystem is Not Evaluated when it is has not yet been assessed against the criteria" (IUCN, 2019). In this category, it means that it was not evaluated in any way within the three components considered within the index.

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