forests

Article

Mangrove Forests in Ecuador: A Two-Decade Analysis

Ramiro Morocho [1,*], Ivonne González [1], Tiago Osorio Ferreira [2] and Xosé Luis Otero [3,4]

[1] Departamento de Ciencias Biológicas y Agropecuarias, Universidad Técnica Particular de Loja, San Cayetano s/n, Loja 1101608, Ecuador; imgonzalez3@utpl.edu.ec
[2] Luiz de Queiroz College of Agriculture, University of Sao Paulo (Escola Superior de Agricultura Luiz de Queiroz), Av. Padua Dias 11, Piracicaba, Sao Paulo 13418-900, Brazil; toferreira@usp.br
[3] CRETUS, Departamento de Edafoloxía e Química Agrícola, Facultade de Bioloxía, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Spain; xl.otero@usc.es
[4] Rede de Estacións Biolóxicas da Universidade de Santiago de Compostela, Rede de Estacións Biolóxicas da USC, Casa do Hórreo, Rúa da Ribeira, 1–4, 15590 A Graña–Ferrol, Spain
* Correspondence: jrmorocho@utpl.edu.ec; Tel.: +593-7-370-1444

Abstract: Mangroves are one of the most important ecosystems especially due to the services they provide, but in contrast are one of the most threatened by human activities at a global level. In Ecuador, mangrove forests are currently fragile and threatened due to the great anthropic pressure, which has largely reduced the area they occupy. However, there is already evidence that certain actions are contributing both to their conservation and the recovery of the lost mangrove area. In this study, we assessed the multitemporal dynamics of changes in mangrove cover in four coastal provinces of the country over a period of 20 years (1998–2018) based on remote sensing data analyzed using GIS tools. Our results showed that the area affected by mangrove forest destruction reached its maximum during the 1998–2010 period, when 4.56% (194.57 km^2) of the mangrove forest was lost. This situation especially affected the provinces of El Oro and Guayas. The main cause for the loss of mangrove cover was the expansion of shrimp farms, followed by agriculture and construction. However, a slight recovery of ~2.9% has been observed, although loss remains constant. Mangrove ecosystem conservation policies, mainly applied to zones within protected areas; the establishment of use and custody agreements and the halt of shrimp farm expansion; the development of mangrove forests on areas with sediment deposits; and natural mangrove recovery processes are key factors for mangrove restoration. These results suggest that it is possible to continue restoring mangrove cover and thus maintain some of the main ecosystem services they provide for the benefit of humans.

Keywords: land cover change; remote sensing; multitemporal changes; GIS

check for updates

Citation: Morocho, R.; González, I.; Ferreira, T.O.; Otero, X.L. Mangrove Forests in Ecuador: A Two-Decade Analysis. *Forests* **2022**, *13*, 656. https://doi.org/10.3390/f13050656

Academic Editor: Timothy A. Martin

Received: 21 February 2022
Accepted: 20 April 2022
Published: 23 April 2022

1. Introduction

Mangrove forests are located at the confluence of land and sea in the world's subtropical and tropical regions [1–4]. They possess characteristics that make them structurally and functionally unique [1]. These forests are hot spots for biodiversity, and provide important and valuable ecosystem services, including coastal protection and fish production, and they are also efficient carbon sinks [3,5–7]. Thus, mangroves provide vital climate change mitigation and adaptation services [2].

Mangroves are among the most productive coastal ecosystems [8,9], contributing to the subsistence of forest-dependent communities and their livelihoods [10].

However, despite the great importance of these unique coastal ecosystems, their destruction and loss have intensified worldwide in the last decades [11]. Mangroves have experienced significant losses, globally declining from 136,798 km^2 in 2000 to 135,882 km^2 in 2016 [12]. Since then, global mangrove deforestation has remained, although at much lower rates, between 0.16% and 0.39% per year [13]. Studies suggest that they could have originally occupied over 200,000 km^2 and that considerably more than 50,000 km^2, or one quarter, of the original mangrove cover have been lost because of human activities [14].

Losses occur especially in developing countries, where more than 90% of the world's mangroves are located [14]. In fact, destruction and degradation are reaching alarming levels in tropical regions, where these ecosystems flourish. Areas where dramatic changes are taking place include countries in Southeast Asia, such as Indonesia, Bangladesh, India, Vietnam, Singapore, Philippines, Thailand, and Myanmar; and in Africa, such as Nigeria, Tanzania, and Guinea-Bissau. Meanwhile, in the Americas, substantial changes are evident in French Guyana, Brazil, México, Perú, Colombia, Venezuela, and Ecuador [1,12,15,16].

Multiple forces drive global mangrove loss, of which nature and dynamics can vary dramatically across regional and local contexts [17]. The greatest driver for mangrove forest loss is the conversion to aquacultural, agricultural, and urban land uses [8]. In Ecuador, mangroves have been explored for timber, charcoal, and tannins, but the most frequent impact has been the conversion of mangrove land to aquaculture, salt production, and agriculture [18].

Mangrove forests in Ecuador are concentrated around river estuaries [18]. The major areas are located along the estuaries of rivers Mataje-Santiago-Cayapas, Muisne, Cojimíes, Chone, Guayas, and Jubones-Santa Rosa-Arenillas [19]. Based on the monitoring of mangrove forests carried out by the Centro de Levantamientos Integrados de Recursos Naturales—CLIRSEN, Instituto Ecuatoriano Forestal y de Áreas Naturales y Vida Silvestre—INEFAN, and other authors, their area has declined from 2022 km^2 in 1969 to 1485 km^2 in 1999 [20].

According to the national classification of ecosystems [21], in Ecuador, we found two vegetation formations: the Chocó Equatorial mangrove (Esmeraldas) and the Jama-Zapotillo mangrove (Manabí, Guayas, and El Oro). The Chocó Equatorial area has a pluvial bioclimate with humid ombrotype, while the Jama-Zapotillo area has a xeric bioclimate with dry ombrotype [21,22]. Mangrove forests are mainly composed of well-known major mangrove species: *Rhizophora mangle* L., *R. racemose* G. Mey, *R.* × *harrisonii* Leechm., *Laguncularia racemosa* (L.) C.F. Gaertn. *var. racemosa*, *L. racemosa var. glabriflora* (C. Presl) Stace, *and Avicennia germinans* (L.) L. [20,23,24]. *Rhizophora mangle* L. accounts for between 80% and 90% of all mangrove forests, while the remaining 10% consists mainly of *Avicennia germinans* (L.) L. and *Laguncularia racemose* (L.) [25,26].

Due to the relevant role that mangrove forests play in the conservation of biodiversity and coastal productivity, coastal protection, and in the fight against climate change, it is essential to understand how the area they cover has changed over time [4]. In this sense, remote sensing technologies constitute efficient, fast, and reliable tools for its study. Remote sensing plays an important role in coastal monitoring in many tropical regions, where detailed estimates of changes in forest cover are still necessary due to the impact of these changes on sustainable development and on the environment [27,28].

This study aimed to assess the spatiotemporal dynamics of mangroves in Ecuador. We performed a two-decade assessment using GIS and remote sensing technology. Thus, we detected, identified, mapped, and tracked mangrove conditions and changes [29]. Our results contribute to a better understanding of the current status of mangroves. Moreover, analyzing changes in land use provides valuable insights about deforestation hotspots. Finally, these data contribute to the analysis of the effectiveness of mangrove conservation efforts.

2. Materials and Methods

2.1. Defining the Potential Area Occupied by Mangrove Forests

This study focused on mangrove forests along the Ecuadorian Pacific coastline, located in the provinces of Esmeraldas, Manabí, Guayas, and El Oro. To define the study area, we used the following criteria: (I) previous mangrove cover (official cartography from the Ministry of Water, Environment and Ecological Transition—MAATE), (II) topography (flat coastal plains), (III) distance from coastline (up to 4 km), and (IV) tidal range (up to 3 m) [25]. We combined these criteria through the map overlay technique in order to determine suitable areas for potential mangrove growth (Figure 1).

Figure 1. Potential distribution of mangrove forests along the Ecuadorian coastline.

2.2. Data Sources and Preprocessing

The climatic characteristics of the study area made it difficult to capture clear images across the whole area, especially by presence of cloud cover. In this context, national studies carried out by state agencies constitute a good option to provide baseline data about the previous extent of mangrove forests [30]. Therefore, different data sources were combined for this study: (i) official cartography, (ii) medium-resolution imagery, and (iii) high-resolution imagery.

2.2.1. Official Cartography

Some researchers have used maps from official agencies as a reference for mangrove extent when high quality imagery was not available [30–32]. In Ecuador, the Ministry of Water, Environment, and Ecological Transition (MAATE) is responsible for generating land cover and land use maps within the context of the Land Cover/Land Use of Continental Ecuador Project. Historical land cover maps corresponding to the years of 2000, 2008, and 2016 at a scale of 1:100,000 were obtained from the Interactive Environmental Map web platform. In the case of the first year of analysis for the province of Guayas, we used this information from MAATE because no good quality satellite images were found for visual interpretation.

2.2.2. Medium-Resolution Imagery

For this study, satellite images from Landsat and Sentinel scenes were obtained from the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov/ accessed on 16 January 2018) (Table 1). L1TP products with the lowest possible percentage of cloud cover (less than 20%) were selected [33]. Visual interpretation was performed based on RGB composites from these images. RGB composites help distinguish the different types of land cover and land use. Satellite data with medium spatial resolution, such as those from Landsat and Sentinel, provide adequate spatial details for mapping mangrove areas [34] at the national scale [29].

Table 1. Medium-resolution imagery used in this study.

No.	Name	Province	Path-Row	Date	Resolution
1	LANDSAT 5	Esmeraldas	010-059	8 March 1998	30
2	LANDSAT 5		011-059	3 April 1999	30
3	LANDSAT 5		011-060	19 June 1998	30
4	LANDSAT 7		010-059	4 March 2017	30
5	LANDSAT 7		011-059	22 January 2017	30
6	LANDSAT 7		011-060	22 January 2017	30
7	LANDSAT 5	Manabí	011-060	19 June 1998	30
8	LANDSAT 5		011-061	16 April 1998	30
9	LANDSAT 8		011-060	17 April 2016	30
10	LANDSAT 8		011-061	17 April 2016	30
14	LANDSAT 8	Guayas	010-062	27 February 2018	30
15	LANDSAT 8		011-061	6 May 2017	30
16	LANDSAT 8		011-062	13 October 2017	30
17	LANDSAT 5	El Oro	010-062	20 February 1998	30
18	LANDSAT 5		011-062	3 April 1999	30
19	LANDSAT 5		011-062	6 October 1997	30
20	SENTINEL 2		T17MNS	22 April 2018	20
21	SENTINEL 2		T17MPS	22 April 2018	20

2.2.3. High-Resolution Imagery

From 2010 to 2014, the Ministry of Agriculture developed a Project called SIGTIERRAS which generated aerial photograph imagery at a national level. Aerial photographs from SIGTIERRAS are orthorectified and have a 1 m spatial resolution. These orthophotographs were downloaded from the SIGTIERRAS website (http://www.sigtierras.gob.ec/descargas/ accessed on 16 January 2018), considering that the aerial photography can provide suitable information for highly detailed mapping in small and narrow coastal environments [29,34]. The information for the second year of analysis for all provinces was obtained from the interpretation of these photographs.

2.3. Classification of Images

The classification strategy applied in this study is an adaptation of the classification system proposed by MAATE within the Land Use/Land Cover of Continental Ecuador Project. We employed the first level of this classification system to define general categories that represented land cover patterns in the study area (Table 2).

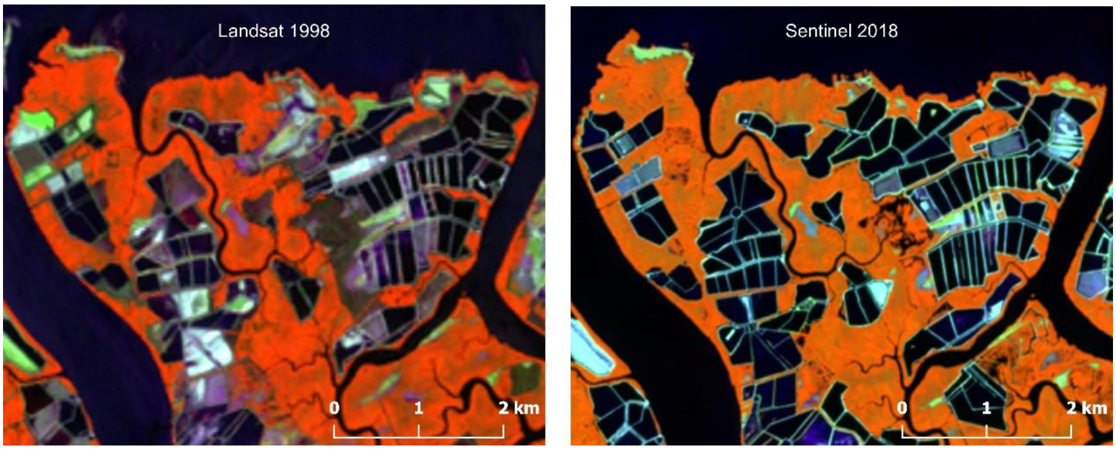
Table 2. Classification system with the land use and land cover categories (LULC) applied in this study.

MAATE Classification System	Adapted Category	Description
Forest	Mangrove	Trees and shrubs in the coastal intertidal zone
Shrub and grass	Natural vegetation	Forests and shrubs in flooded zones
Agricultural land	Cropland	Crops, pastures for livestock, arable areas, logging
Anthropic areas	Built-up area	Artificial structures (buildings, roads, coastal infrastructure)
	Shrimp farming	Active and inactive shrimp ponds
Water bodies	Water	Rivers and estuaries
Other lands	Bare land	Sandy and rocky areas

The following pictures illustrate the land use and land cover categories in the study area (Figure 2).

Figure 2. Representation of land use and land cover categories: (**a**) water; (**b**) shrimp farming; (**c**) built-up area; (**d**) cropland; (**e**) mangrove; (**f**) natural vegetation; and (**g**) bare land.

After establishing the classification scheme, we digitized LULC maps for two periods (1998–2010; 2010–2018). We used a frequently applied method consisting of visual interpretation followed by on-screen digitizing [29]. This method avoids errors that are generated when using automatic classification methods. On-screen digitizing is a way to trace features from images. This is one of the most accurate techniques for characterizing land cover [35]. For the visual interpretation of satellite images, we created false color composites. For Landsat imagery, we applied an RGB composite using near infrared (NIR), shortwave infrared (SWIR), and red bands. For Sentinel 2A imagery, we applied a band composite using vegetation red edge, shortwave infrared (SWIR), and red bands (Figure 3). These composites are capable of distinguishing mangrove forest from the surrounding objects more clearly [36].



(a) (b)

Figure 3. (**a**) Landsat RGB image combines the near infrared (NIR), shortwave infrared (SWIR), and red bands, (**b**) sentinel 2A RGB image combines the vegetation red edge, shortwave infrared (SWIR), and red bands. These composites display mangrove forests in a reddish-brown color.

LULC maps of each province were generated for three different periods which were established according to data availability (Table 3).

Table 3. Years analyzed by province.

Province	Year 1 (Y1)	Year 2 (Y2)	Year 3 (Y3)
Esmeraldas	1998	2010	2017
Manabí	1998	2010	2017
Guayas	2000	2011	2016
El Oro	1997	2011	2018

Based on the map for the first year (Y1), the FAO interdependent classification method [37] was applied to generate maps for the second and third years (Y2 and Y3). This approach consists of comparing polygons in the first map with images from subsequent dates, modifying only those segments where changes are detected [38]. According to Ramírez and Zubieta [39], interdependent classification is an accurate technique since it reduces classification and position errors.

2.4. Accuracy Assessment

We compared maps Y1, Y2, and Y3 with imagery hosted by Google Earth Engine and high-resolution Google Earth (GE) imagery, where available. Some studies have shown that high-resolution images from GE have an overall positional accuracy close to 1 m, sufficient for deriving ground truth samples [40]. We determined a minimum sample size of 50 points for each LUC category, as recommended by Congalton and Green [41] for classifications with less than 12 categories. A total of 4200 sample points were randomly generated for the entire area and study periods (Table 4). Accordingly, a confusion matrix technique was applied to assess the accuracy of the classification. Overall accuracy and the kappa coefficient were calculated to verify map classification [42].

Table 4. Details of sample points by province and LUC.

Province	Mangrove	Shrimp Farming	Built-Up Land	Cropland	Natural Vegetation	Water	Bare Land	Total
El Oro	50	50	50	50	50	50	50	350
Esmeraldas	50	50	50	50	50	50	50	350
Guayas	50	50	50	50	50	50	50	350
Manabi	50	50	50	50	50	50	50	350
Total	200	200	200	200	200	200	200	1400 *

* Total of sample points generated per year.

2.5. Detection of Changes

Map overlay between any two points in time generates a cross tabulation matrix, where rows show the categories from an initial time point, columns show the categories from a subsequent time point, and entries show the size of the area that transitioned from the initial to the subsequent category during the time interval. Entries on the diagonal indicate persistence of land categories, while entries off the diagonal show changes in land use categories [43].

3. Results and Discussion

3.1. Accuracy Assesment

Table 5 summarizes the results from accuracy assessment. For all classifications, the overall accuracy was above 80%. Kappa coefficient values were above 0.75 for all classified maps. Rwanga and Ndmbuki [44] classified kappa values of 0.61–0.8 as substantial and 0.81–1 as almost perfect agreement. Thus, the classifications were accurate enough to perform further analysis.

Table 5. Accuracy assessment and kappa coefficient values.

Province/Year	Overall Accuracy	Kappa Coefficient
El Oro Y1	83.82	0.76
El Oro Y2	89.77	0.85
El Oro Y3	87.87	0.82
Esmeraldas Y1	84.31	0.81
Esmeraldas Y2	85.98	0.82
Esmeraldas Y3	85.82	0.82
Guayas Y1	81.25	0.76
Guayas Y2	83.07	0.79
Guayas Y3	80.10	0.75
Manabí Y1	84.73	0.80
Manabí Y2	87.05	0.83
Manabí Y3	86.13	0.82

We obtained good results with the visual interpretation method. This method usually presents less classification errors than automatic classification [38]. However, this approach has some limitations such as the differences among interpreters' perceptions and problems during digitization derived from image quality (atmospheric conditions, brightness, stereoscopic effects, cast shadows, contrast, mixed pixels, and geometric resolution) [45]. It is important to note that Guayas Y1 map obtained from the MAATE database has an acceptable accuracy, even though it was generated through automated classification. Regardless of the accuracy, we must point out that classified maps also have uncertainty, thus the findings we describe in the next sections must be considered as estimates instead of exact measurements.

3.2. Changes in Mangrove-Covered Area

We analyzed the quantity of LULC types in all LULC categories for each study period (Figure 4). Mangrove and shrimp farming were the dominant LULC types in the study area. These categories represented more than 50% of the total area in each province.

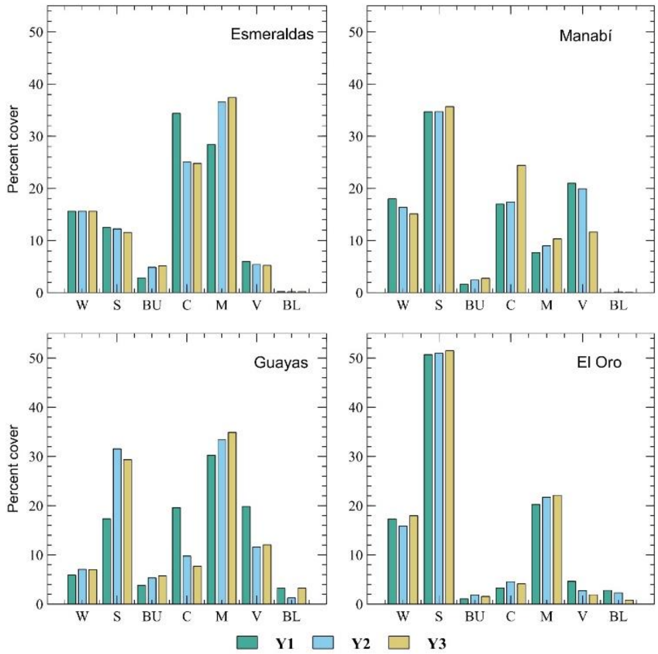


Figure 4. Percent cover of each LULC type by province during Y1, Y2, and Y3 (see Table 3). LULC types are: water (W), shrimp farming (S), built-up land (BU), cropland (C), mangrove (M), natural vegetation (V), and bare land (BL).

Mangroves in Ecuador have been suffering a degradation process since the 1960s [17,46]. According to CLIRSEN [47], in 1987, mangroves covered an area of 1751 km^2. The present results show that the area covered by mangroves in 1998 was 1484 km^2, suggesting a loss of 267 km^2. By 2010, this area had slightly increased to 1580.9 km^2, which entails the recovery of at least 96.9 km^2 of mangrove. Finally, by 2018, the mangrove-covered area was 1645.2 km^2, indicating an increase of 64.3 km^2 in mangrove cover. Overall, the analysis of net changes in mangrove cover showed a slight increase (2.9%) between the initial and final periods (Table 6).

Table 6. Changes in land cover and use-type cover in the three study years.

Land Cover/Use Type	1998		2010		2018	
	km^2	%	km^2	%	km^2	%
Water	557.0	10.0	556.6	10.0	565.6	10.1
Shrimp farming	1301.7	23.3	1662.5	29.8	1594.1	28.5
Built-up area	172.2	3.1	237.5	4.3	250.4	4.5
Cropland	1070.4	19.2	634.1	11.4	595.1	10.7
Mangrove	1484.0	26.6	1580.9	28.3	1645.2	29.5
Natural vegetation	864.6	15.5	853.6	15.3	821.5	14.7
Bare land	136.3	2.4	61.0	1.1	114.0	2.0

In Ecuador, different plans have been implemented since 1949 to allow for the sustainable exploitation of mangrove forests, particularly focusing on timber use for shipbuilding, railways, and exports [48].

Historical mangrove degradation has been mainly linked to the expansion of shrimp aquaculture [49]. Shrimp farms were established on the tidal flats where mangrove forests grow, causing mangrove deforestation [50]. As reported by CLIRSEN [47], the uncontrolled expansion of the shrimp farming industry in Ecuador within less than 30 years, is the main cause for mangrove alteration and loss [15,51]. It is worth considering that, despite the great social, economic, and environmental value of this ecosystem for the population, shrimp farming is the activity that generates the highest revenue in Ecuador followed by the oil industry. Shrimp farming reached a total revenue of USD 3823.53 million in 2020, accounting for 25.53% of the country's non-oil exports and 18.90% of the total exports of Ecuador [52].

The present study confirmed that the expansion of shrimp farming has slowed down in recent years. This result is in line with findings by Hamilton et al. [50] who considered the following periods: (i) 1970–1990, rapid deforestation; (ii) 1990–2000, stabilization period; and (iii) 2000–2010, recovery period. The period analyzed in this study matches the two latter periods proposed by Hamilton et al. [25]; therefore, a positive balance in mangrove recovery was observed.

Our data suggest that conservation policies implemented 20 years ago have allowed the recovery of around 161.20 km^2 of mangrove forests in Ecuador. On the other hand, it is worth noting that during the first period, the area covered by shrimp farms increased by 6.5%, while during the second period, this area started to gradually decrease (−1.3%; Figure 4 and Table 6). Despite the efforts made to implement sustainable policies for mangrove management, the development of shrimp farming has led to illegal land concessions, authorizations for mangrove clearing without meeting the legally established requirements, and land-buying from local communities [48].

It is also worth pointing out that in all periods, the area covered by water bodies gradually decreased from 557.0 km^2 (1998) to 556.6 km^2 (2010) and finally, to 565.6 km^2 (2018). This suggests that, given the mangroves' sediment retention dynamics, new mangrove-covered spaces may have been generated, contributing to the increase in their cover area [53].

"Natural vegetation" gradually decreased by 0.8% from 1998 (15.5%) to 2018 (14.7%). This result suggests that anthropogenic activities also affected other type of vegetation besides mangrove.

A particular case was found in the coastal region of the Esmeraldas province, where a net 9% increase in mangrove-covered area was observed between 1998 and 2018. The built-up land cover category showed a 3% increase within the same period. Cropland was the category with the largest net loss, with almost 10%, while shrimp farming and natural vegetation have decreased by 1%. An example of these occupation dynamics and the abandonment of shrimp farms can be found in the Bocana de Limones sector (Figure 5).

(**a**) (**b**) (**c**)

Figure 5. Land occupation and abandonment of shrimp farms in the Bocana de Limones sector, in the Esmeraldas province. (**a**) In the 1998 satellite image, shrimp ponds are shown in dark color and mangroves are shown in reddish-brown; (**b**) in the 2010 satellite image, some abandoned pools with recovering mangroves can be observed; (**c**) finally, in the 2018 satellite image, abandoned shrimp farms covered by mangroves can be observed on the left and right sides.

Net change data suggested that conservation policies in Esmeraldas have contributed to mangrove recovery and to halting the expansion of shrimp farming. This could also be due to the existence of three protected areas in this region: the Manglares Cayapa Mataje Ecological Reserve, Manglares del río Muisne, and Manglares del río Esmeraldas Wildlife Refuges. Moreover, the existence of 18 agreements for the sustainable use of mangroves by users with ancestral rights has been reported, although only five of them were still in force by 2019. Similar trends have been observed in mangrove forests within protected areas in other regions of the world, such as the Saadani National Park in Tanzania [54] or the Futian Mangrove National Nature Reserve and the Mai Po Marshes Nature Reserve in China [55,56].

Mangrove forests in El Oro occupied around 234 km^2 in 1987. In the same year, shrimp farms covered 297 km^2 [47]. According to our data, in 1997, there were nearly 164 km^2 of mangrove forests and 411 km^2 of shrimp ponds. This means that between 1987 and 1997, El Oro lost approximately 30% of its mangrove cover. Conversely, during the same period, the area occupied by shrimp farms almost doubled. From 1997 to 2018, our data showed a slightly increasing trend in both mangrove (1.9%) and shrimp farms (0.7%) (Figure 4). Thus, it could be suggested that these categories have become stable in El Oro.

In Guayas, the mangrove-covered area barely increased during the first period (0.26%), while the area covered by shrimp farms experienced a significant growth of 10.4%. (5.5% (Figure 4). During the second period, the mangrove-covered area increased 1.38%, (8.6%) while shrimp farms had a minimum decrease of 2.04%. This result appears to be related to a positive impact of the executive decrees No. 1391 and No. 852, issued by the Government of Ecuador in 2008 and 2016, respectively. These decrees regulate shrimp enterprises expansion [51]. In Manabí, a positive balance in mangrove cover was observed for both periods (with a 2.6% net increase; Figure 4). While only three sustainable use agreements are in force in this province, it is worth noting the creation of the Islas Corazón y Fragatas Wildlife Refuge in 2002, mainly aimed at the protection and restoration of the mangrove ecosystem.

3.3. Interactions between Anthropogenic Activities and Mangroves

In line with previous studies, the net change data showed that land use in the region under analysis has undergone little change. However, cross-tabulation analysis (Table 7) revealed that mangrove was the category with the highest values for swap and total change indicators. This means that approximately 19% of mangrove cover has been subject to permanent loss and gain processes (swap P1 and swap P2). A similar pattern of results worldwide was mentioned by De Lacerda et al. [57]. They indicate that despite a slight reduction in forest loss rates, mangrove clearing and fragmentation continues.

Given the fragility of mangrove forests, constant alterations can negatively impact the health of the mangrove not only in terms of cover but also of water, soil, and fauna [12]. Therefore, programs should be developed to monitor the restoration process to avoid changes in land use, considering that mangrove recovery can require at least five years. Mangroves may recover after storms with minimal or no intervention, as long as elevation and hydrology have not been deeply affected (for example, due to sediment loss) [58]. In many aspects, mangroves act like weed species and can grow quickly in an intertidal environment with few competitors. Overall, their natural recovery is often faster than any other marine ecosystem. Initial recovery can be observed within 3–5 years, when new generations of mangroves are able to take hold, although the full recovery of an ecologically functional forest can take longer [59].

Table 7. Indicators of change in the different land use categories *.

Categories	Persistence P1	Persistence P2	Loss P1	Loss P2	Gain P1	Gain P2	Total Change P1	Total Change P2	Swap P1	Swap P2	Net Change P1	Net Change P2
Water	9.01	7.08	2.26	3.55	1.62	3.74	3.89	7.29	3.24	7.10	0.64	0.19
Shrimp farming	22.54	20.80	2.01	10.97	9.23	9.67	11.24	20.65	4.03	19.34	7.22	1.30
Built-up land	3.03	3.94	0.22	0.53	1.44	0.78	1.66	1.31	0.44	1.06	1.22	0.25
Cropland	9.05	8.91	11.61	3.17	3.02	2.40	14.64	5.57	6.05	4.80	8.59	0.77
Mangrove	24.63	25.15	4.56	4.99	5.51	6.22	10.08	11.21	9.13	9.98	0.95	1.24
Natural vegetation	5.98	7.42	2.47	2.34	3.77	1.76	6.24	4.09	4.94	3.51	1.31	0.58
Bare land	0.31	0.29	2.31	0.88	0.85	1.85	3.16	2.73	1.70	1.76	1.46	0.97
Total	74.54	73.58	25.46	26.42	25.46	26.42	50.91	52.84	29.52	47.54	21.39	5.30

* Values are expressed as percentage of the landscape for each category at the initial time point for each period. P1: 1998–2010, P2: 2010–2018.

The provinces with the highest degree of mangrove losses during the study periods were Guayas > El Oro > Esmeraldas > Manabí (Table 8), contrasting with the findings by CLIRSEN [47], which evidenced that the provinces with the greatest loss were El Oro > Guayas > Manabí > Esmeraldas. Gross losses highlighted the existence of some areas subject to deforestation. Generally, these areas lack any legal protection or custody.

Table 8. Mangrove gross losses and gains by province *.

Province	Year 1–Year 2 (P1)		Year 2–Year 3 (P2)	
	Loss	Gain	Loss	Gain
El Oro	37.63	49.70	8.73	12.16
Esmeraldas	25.69	95.63	6.22	13.48
Guayas	119.65	120.67	72.23	120.20
Manabí	11.60	17.27	6.34	12.13

* Estimated lost and gained areas in km^2 for Periods 1 and 2.

The analysis of mangrove gross losses allowed detection of deforestation hotspots. The rate of deforestation in these hotspots was higher in Manabí and El Oro during P1. In P2, we found slower loss rates in all the provinces, except for Guayas (Figure 6).

Although shrimp farming has declined since the 1990s, mangroves face different anthropic pressures such as wood extraction, oil-palm production, coastal development, and urban sprawl [17,20,60]. Conversely, our study revealed that other anthropic activities, although to a smaller degree, have generated major changes in mangrove cover. These activities consist mainly of the development of human settlements and touristic infrastructure. Moreover, change indicators warn about continued changes over time, leading to potentially irreversible transformations of mangrove forests [61].

As shown in Table 7, these categories have contributed to mangrove loss and gain in the province of Esmeraldas. As for shrimp farming, a pattern of permanent occupation followed by abandonment of the ponds could be observed in association with natural mangrove recovery, mainly in the Muisne and Esmeraldas River estuaries. In Esmeraldas, the Cayapas-Mataje protected area was the location with the greatest mangrove forest recovery (Figure 7).

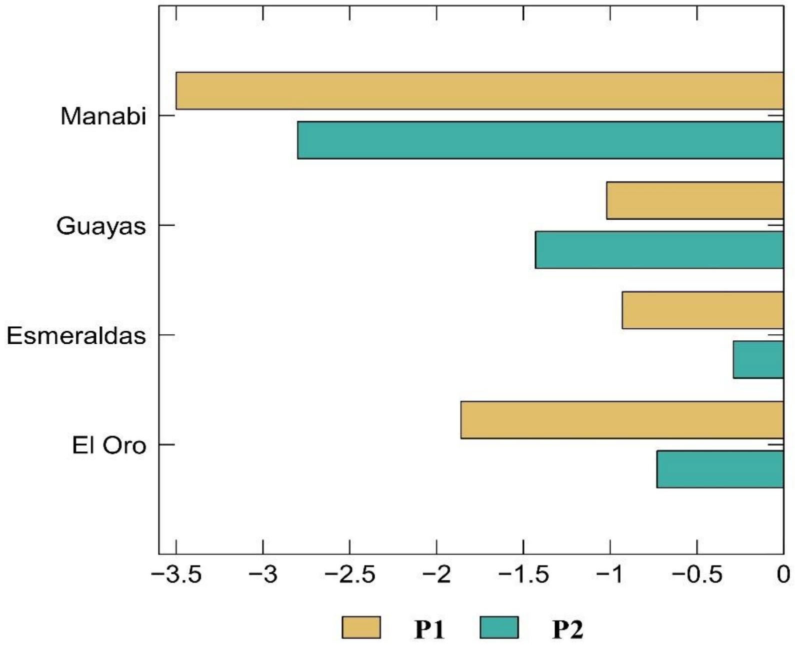


Figure 6. Mangrove loss rates by province. P1: 1998–2010, P2: 2010–2018.

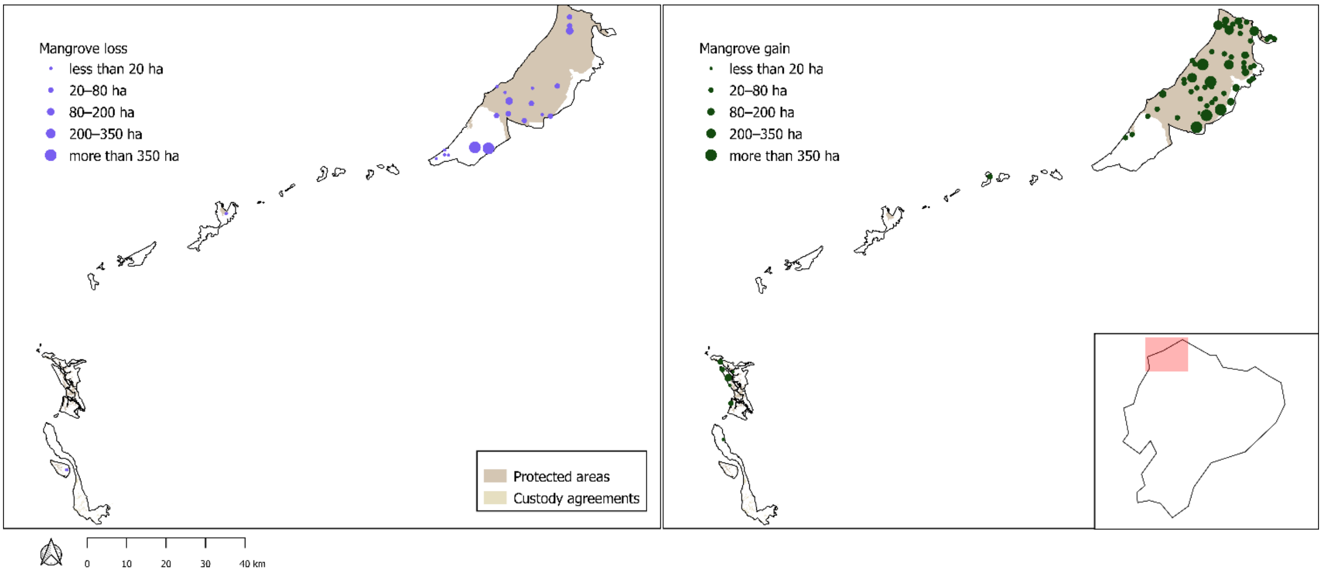


Figure 7. Mangrove losses and gains in the Esmeraldas province between 1998 and 2016.

As for the province of Manabí (Figure 8), gains greatly exceeded losses, mainly in the Chone river estuary (in the south of the province) and in the Chamanga area (in the north of the province), where three custody agreements exist. Although recovery in the Chone estuary has been remarkable, the pressure from shrimp farming continued to gradually degrade mangroves.

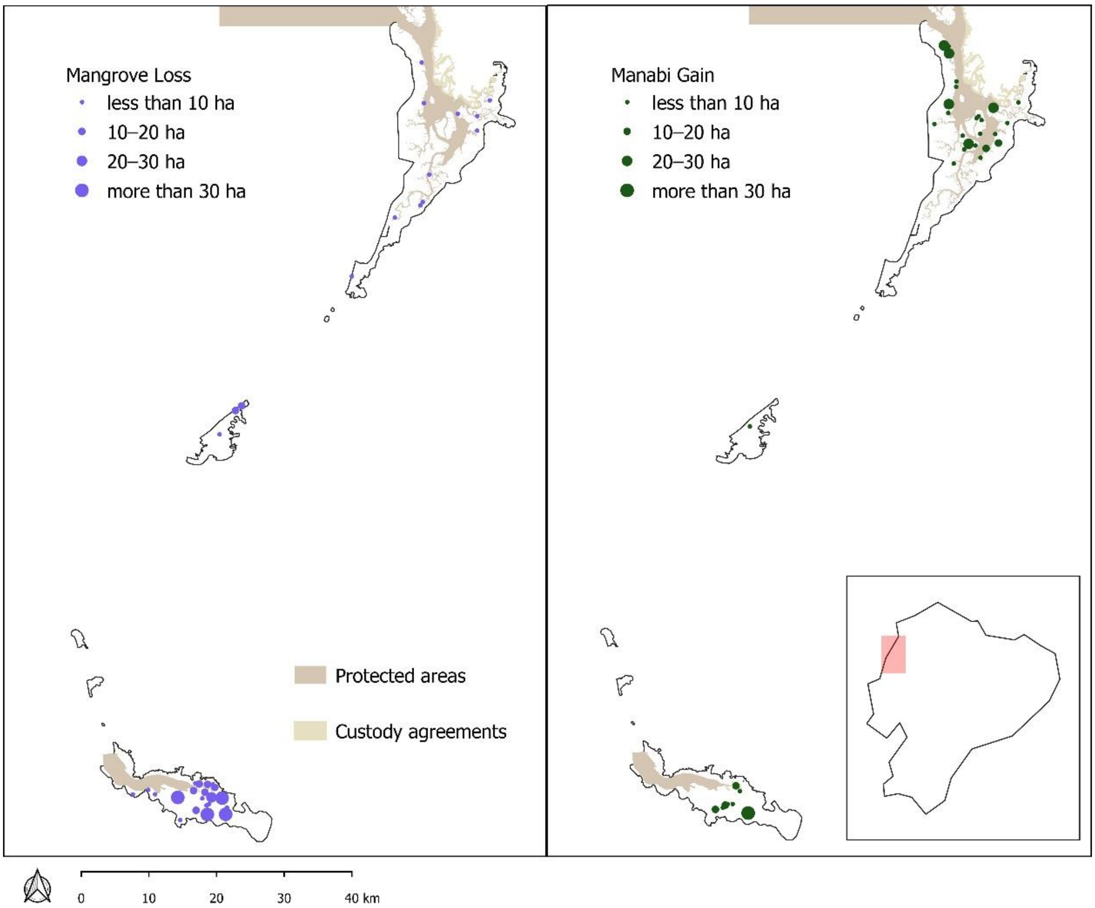


Figure 8. Mangrove losses and gains in the Manabí province between 1998 and 2016.

The same trend could be observed in the province of Guayas (Figure 9), with the constant occupation and abandonment of areas dedicated to crops and shrimp farming activities; however, it is also worth noting the recovery of mangrove areas, often related to conservation and recovery initiatives through the establishment of agreements for the sustainable use and custody of mangroves (AUSCM). This was the case of the Guayas river estuary, which comprises a large portion of the Gulf of Guayaquil and Puná Island.

Finally, in the case of El Oro province (Figure 10), the continuous interspersion between shrimp farming and mangrove recovery areas was much more evident, although the latter slightly predominated, mostly owing to areas under the protection of AUSCM. This process was the most notable in the Jambelí archipelago.

Generally, the interactions occurring to the detriment of the mangrove ecosystem and resulting in a decrease in its area were closely linked mainly to shrimp farming; however, they have been proven possible to control through the design and enforcement of adequate conservation and sustainable use policies, as well as with the establishment of protected areas that include representative sites within these ecosystems.

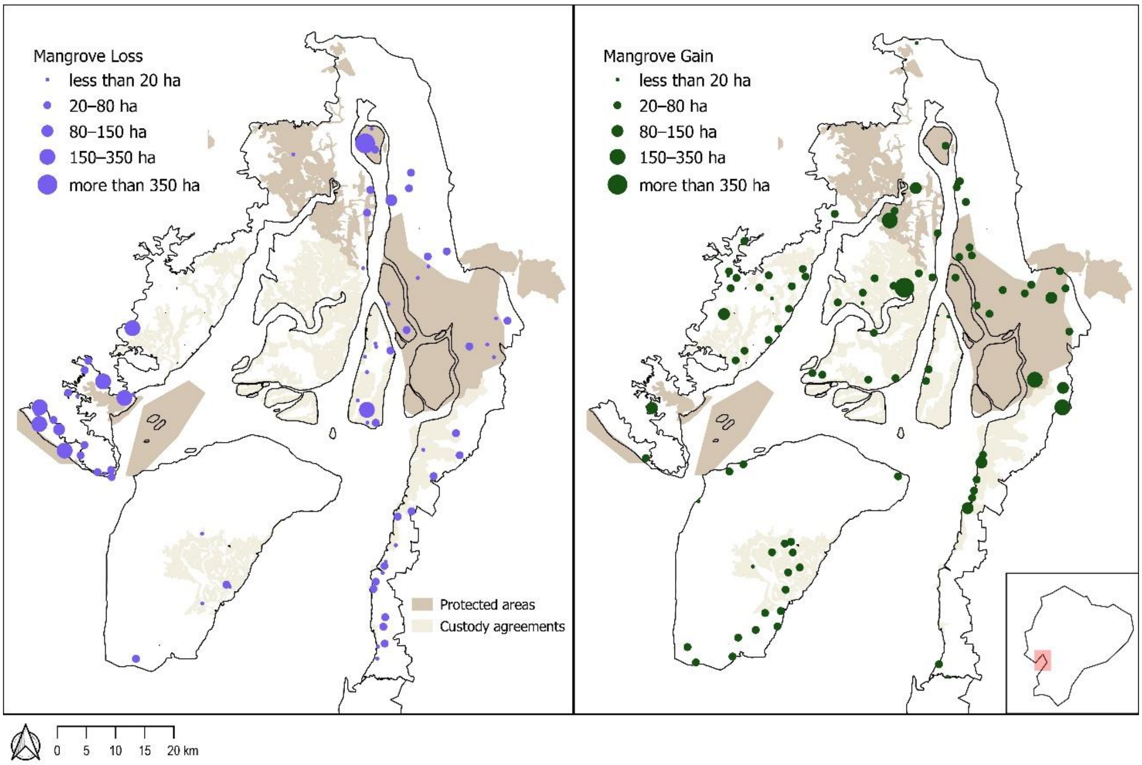


Figure 9. Mangrove losses and gains in the Guayas province between 1984 and 2016.

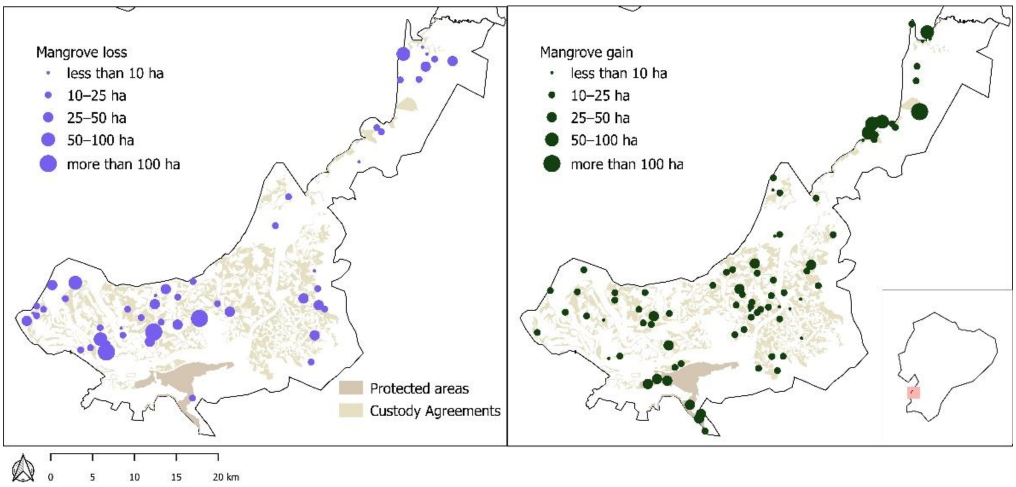


Figure 10. Mangrove losses and gains in the province of El Oro between 1997 and 2018.

The analysis of changes also revealed that other processes were also contributing to mangrove degradation, although to a smaller extent; for example, anthropic activities such as crop cultivation (such as African oil palm), urban expansion, and construction of port and touristic infrastructures. Coastal erosion processes were also evidenced, altering mangrove vegetation and accelerating water flow on the soil surfaces, in turn resulting in transport of sediments away from the area. When this situation is sustained over time, it can lead to loss of mangroves, changes in sediment movement pattern, and loss of land to sea [62] (Figure 11).

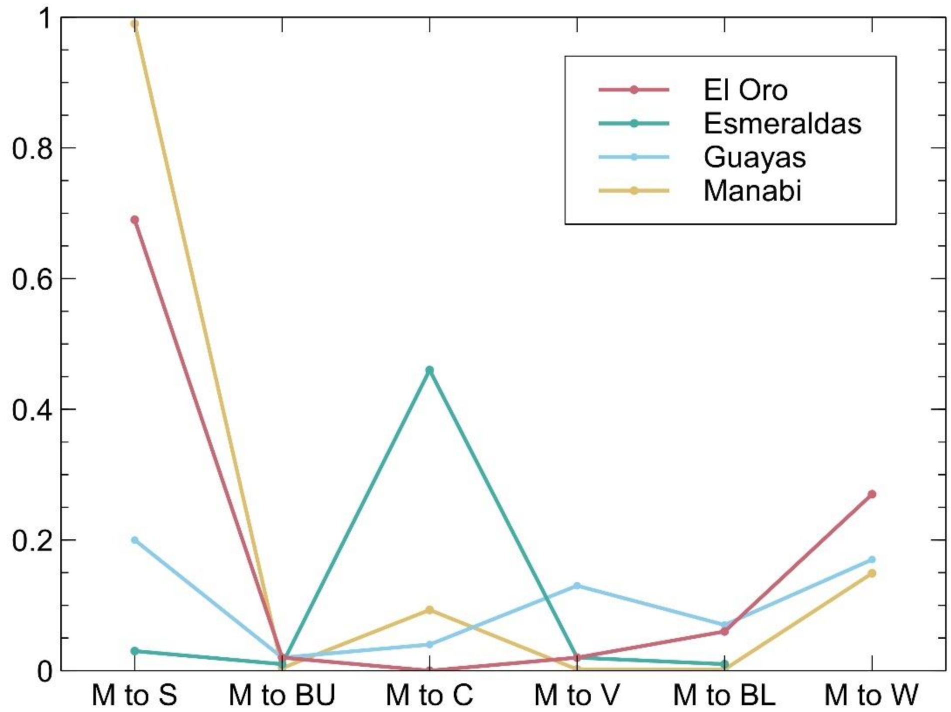


Figure 11. Intensity of annual change from mangrove to other cover categories (period 2010–2018), represented according to the following equation: Rtin = *transition area from i to n during time period n/duration of the period area of category i to time n* × 100.

Natural vegetation category is the result of changes in areas originally covered by mangrove, but which could not be restored and have instead become part of neighboring ecosystems, such as brush. In this analysis, low vegetation refers to land with low plant cover density, resulting from the transition or lag period from mangrove conversion to aquaculture. After mangroves are cut, these areas are often left for a certain period before they are turned into ponds. During this lag period, new vegetation such as shrubs, grasses, and even bare lands takes over the former mangrove area [63]. Among the actions that best represented a contribution to the increase in areas covered by mangroves was the establishment of national protected areas within the National System of Protected Areas (Sistema Nacional de Áreas Protegidas, SNAP) or of areas under sustainable use and conservation agreements, such as the Áreas de Uso Sustentable y Custodia de Manglar (AUSCM).

While mangrove loss has been constant, actions aiming at the protection and restoration of this ecosystem have proven to be efficient to maintain and increase its cover area. Among these actions, it is worth highlighting the agreements known as AUSCM established in the four studied provinces, which by 2018 covered around 592.08 km^2 [51,64] out of the 1618.35 km^2 of mangroves in the country, i.e., around 37% of the total mangrove cover. The situation is different in areas where no protection or sustainable use figures have been implemented: in these areas located near estuaries, around shrimp pools, or near the AUSCM, the constant loss of mangrove cover is significant.

Overall, the four main estuaries in the provinces of Manabí (Chone river and Cojimíes) and Esmeraldas (Mataje and Esmeraldas), in the north of Ecuador, lost around 209.50 km^2 of mangrove forests between the arrival of aquaculture and the moment of maximum deforestation, while 179.80 km^2 have been lost between the arrival of aquaculture and the most recent survey. This amounts to a 37% decrease in mangrove cover until the moment of maximum mangrove loss. Excluding the Cayapas-Mataje ecological reserve located in the Mataje estuary, mangrove loss in the three remaining estuaries reached 83% by 2000 and is currently at 69%.

According to several authors, communities play a major role in mangrove restoration [65,66]. Studies carried out in the south of Thailand also demonstrated that community-managed protected areas have been more effective for mangrove protection than protected areas under national management. Moreover, similar cases exist, e.g., in Indonesia, Philippines, and Cambodia, where community management has yielded positive results in terms of mangrove cover [67,68].

Similarly, the existence of protected areas such as those belonging to the National System of Protected Areas (SNAP) contributed to the conservation and restoration of the mangrove ecosystem, since the different conservation areas include extensive mangrove forests, which in 2012 accounted for 46.5% of mangroves present in the country, i.e., approximately 730.71 km^2 [51].

4. Conclusions

The spatiotemporal analysis of the evolution of the area covered by mangrove forests in Ecuador determined that:

1. The highest mangrove destruction rate in the country was reached during the 1998–2010 period, resulting in a loss of 194.57 km^2, which amount to 4.56% of the total mangrove area. The most affected provinces were El Oro and Guayas, and shrimp farming activity was the main cause of mangrove loss.
2. Since the 2010–2018 period, a gradual recovery of occupied areas has been observed, especially in the northern province of Esmeraldas and in the southern province of El Oro. This recovery is probably related to the regulation of deforestation, mangrove conservation and restoration initiatives implemented in the Cayapas Mataje ecological reserve, and the implementation of areas under sustainable use and conservation agreements (Áreas de Uso Sustentable y Custodia de Manglar, AUSCM), mainly in the province of El Oro.
3. Infrastructure building, agricultural land use, and construction and maintenance of shrimp farming infrastructure are currently the main causes related to the destruction and loss of new mangrove areas; this process is widespread among all the provinces in the country but has been especially evident in the province of El Oro.
4. The remaining mangrove-covered areas are still subjected to deforestation processes; however, the rate at which these processes occur has been shown to have slowed down compared to two decades ago.

Author Contributions: Conceptualization, I.G. and R.M.; methodology I.G. and R.M.; software, I.G.; validation, I.G. and R.M.; formal analysis, I.G. and R.M.; investigation, I.G. and R.M.; writing—original draft preparation, I.G., R.M., X.L.O. and T.O.F.; writing—review and editing, T.O.F. review and editing, I.G., R.M. and X.L.O.; supervision, X.L.O.; project administration, I.G. and R.M. All authors have read and agreed to the published version of the manuscript.

Funding: This study is part of the program for consolidation of competitive research groups (Axudas consolidación e estruturación de unidades de investigación competitivas do SUG del Plan Galego IDT, Ambiosol Group ref. 2018-PG036), and Cross-Research in Environmental Technologies, CRETUS (Xunta de Galicia GRUP2015/02, ref. 2018-PG100).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available at https://earthexplorer.usgs.gov; http://ide.ambiente.gob.ec/mapainteractivo/; http://www.sigtierras.gob.ec/descargas/ accessed on 16 January 2018.

Acknowledgments: The authors acknowledge the helpful comments received from Alejandro Gómez Pazo (Universidad de Santiago de Compostela) on previous versions of this paper. The authors would also like to thank Jhoony Chalán, Luis Armijos, Fernando Villavicencio, Belén Cañar, and Saymar Gómez for their contribution to pre-processing of the information; Christine Francis for translation and Elsa Morocho and David Coleman Parsons for proofreading and translation.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Alongi, D. Present state and future of the world's mangrove. *Environ. Conserv.* **2002**, *29*, 331–349. [CrossRef]
2. Duncan, C.; Primavera, J.; Pettorelli, N.; Thompson, J.; Loma, R.; Koldewey, H. Rehabilitating mangrove ecosystem services: A case study on the relative benefits of abandoned pond reversion from Panay Island, Philippines. *Mar. Pollut. Bull.* **2016**, *109*, 772–782. [CrossRef] [PubMed]
3. Giri, C.; Ochieng, E.; Tieszen, 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]
4. 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]
5. Otero, X.; Macías, F. *Biogeochemistry and Pedogenetic Proccess in Saltmarsh and Mangrove Systems*; Nova Science Publishers, Inc.: New York, NY, USA, 2010; pp. 36–65.
6. 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]
7. Chmura, G.; Anisfeld, S.; Cahoon, D.; Lynch, J. Global carbon sequestration in tidal, saline wetland soils. *Glob. Biogeochem. Cycles* **2003**, *17*. [CrossRef]
8. Spalding, M.; Kainuma, M.; Collins, L. *World Atlas of Mangroves*; Earhtscan: London, UK; Washington, DC, USA, 2010.
9. Cam-Hong, H.; Avtar, R.; Fujii, M. Monitoring changes in land use and distribution of mangroves in the southeastern part of the Mekong River Delta, Vietnam. *Trop. Ecol.* **2020**, *60*, 552–565. [CrossRef]
10. Aye, W.; Yali, W.; Marin, K.; Thapa, S.; Tun, A. Contribution of Mangrove Forest to the Livelihood of Local Communities in Ayeyarwaddy Region, Myanmar. *Forests* **2019**, *10*, 414. [CrossRef]
11. Mafi-Gholami, D.; Jaafari, A.; Zenner, E.; Nouri Kamari, A.; Tien Bui, D. Spatial modeling of exposure of mangrove ecosystems to multiple environmental hazards. *Sci. Total Environ.* **2020**, *740*, 140167. [CrossRef]
12. Spalding, M.; Leal, M. The state of the world's mangroves 2021. *Glob. Mangrove Alliance* **2021**, 41.
13. Hamilton, S.; 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]
14. Duke, N.; Nagelkerken, I.; Agardy, T.; Wells, S.; Van Lavieren, H. *The Importance of Mangroves to People: A Call to Action*; United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC): Cambridge, UK, 2014; p. 128.
15. DasGupta, R.; Shaw, R. Cumulative Impacts of Human Interventions and Climate Change on Mangrove Ecosystems of South and Southeast Asia: An Overview. *J. Ecosyst.* **2013**, *2013*, 15. [CrossRef]
16. Gorman, D. Historical Losses of Mangrove Systems in South America from Human-Induced and Natural Impacts. In *Threats to Mangrove Forests. Coastal Research Library*; Makowski, C., Finkl, C., Eds.; Springer: Cham, Switzerland, 2018; Volume 25, pp. 155–171.
17. Chowdhury, R.; Uchida, E.; Chen, L.; Osorio, V.; Yoder, L. Anthropogenic Drivers of Mangrove Loss: Geographic Patterns and Implications for Livelihoods. In *Mangrove Ecosystems: A Global Biogeographic Perspective. Structure, Function, and Services*; Rivera-Monroy, V., Lee, S., Kristensen, E., Twilley, R., Eds.; Springer: Cham, Switzerland, 2017; p. 407.
18. Spalding, M.; Blasco, F.; Field, C. *World Mangrove Atlas*; The International Society for Mangrove Ecosystems: Okinawa, Japan, 1997; p. 178.
19. Bodero, A.; Robadue, D. Estrategia para el Manejo del Ecosistema de Manglar, Ecuador. In *Manejo Costero lntegrado en Ecuador*; Ochoa, M., Ed.; Fundación Pedro Vicente Maldonado: Guayaquil, Ecuador, 1995; p. 60.
20. Centro de Levantamientos Integrados de Recursos Naturales por Sensores Remotos—CLIRSEN. Actualización del estudio multitemporal de manglares, camaroneras y áreas salinas en la costa continental ecuatoriana al año 2006. *CLIRSEN Quito Ecuador.* **2007**, *77*.
21. Ministerio del Ambiente del Ecuador—MAE. *Sistema de Clasificación de Ecosistemas del Ecuador Continental*; Subsecretaría de Patrimonio Cultural, Ministerio del Ambiente del Ecuador: Quito, Ecuador, 2013; p. 235.
22. Rivas-Martínez, S. *Global Bioclimatics (Clasificación Bioclimática de la Tierra)*; Versión 27/08/2004; Phytosociological Research Center. Departamento de Biología Vegetal II (Botánica). Facultad de Farmacia. Universidad Complutense de Madrid: Madrid, Spain, 2004; Available online: https://webs.ucm.es/info/cif/book/bioc/global_bioclimatics_2.htm (accessed on 12 December 2021).
23. Ministerio del Ambiente del Ecuador—MAE; Organización de las Naciones Unidas para la Alimentación y la Agricultura, IT—FAO. *Árboles y Arbustos de los Manglares del Ecuador*; MAE-FAO: Quito, Ecuador, 2014; 48p.
24. Cornejo, X. (Ed.) *Plants of the South American Pacific Mangrove Swamps (Colombia, Ecuador, Perú)*; Universidad de Guayaquil, Facultad de Ciencias Naturales: Guayaquil, Ecuador, 2014; 310p.
25. Hamilton, S. *Mangroves and Aquaculture. A five Decades Remote Sensing Analysis of Ecuador ´s Estuarine Environments*; Coastal Research Library: Cham, Switzerland, 2020.
26. Bravo, M. *Alianza Público-Privada Para la Gestión de los Manglares del Ecuador: Los Acuerdos Para el Uso Sustentable y Custodia*; USAID Costas y Bosques Sostenibles: Ecuador, 2013; 85p, Available online: https://docplayer.es (accessed on 20 February 2022).
27. Alesheick, A.; Ghorbanali, A.; Nouri, N. Coastline change detection using remote sensing. *Int. J. Environ. Sci. Tech.* **2007**, *4*, 61–66. [CrossRef]

28. Haro-Carrión, X.; Southworth, J. Understanding Land Cover Change in a Fragmented Forest Landscape in a Biodiversity Hotspot of Coastal Ecuador. *Remote Sens.* **2018**, *10*, 1980. [CrossRef]
29. Kuenzer, C.; Bluemel, A.; Gebhardt, S.; Vo Quoc, T.; Dech, S. Remote Sensing of Mangrove Ecosystems: A Review. *Remote Sens.* **2011**, *3*, 878–928. [CrossRef]
30. Valderrama, L.; Troche, C.; Rodriguez, M.; Marquez, D.; Vázquez, B.; Velázquez, S.; Vázquez, A.; Cruz, M.; Ressl, R. Evaluation of Mangrove Cover Changes in Mexico During the 1970–2005 Period. *Wetlands* **2014**, *34*, 747–758. [CrossRef]
31. Mayaux, P.; Richards, T.; Janodet, E. A vegetation map of Central Africa derived from satellite imagery. *J. Biogeogr.* **1999**, *25*, 353–366. [CrossRef]
32. Liu, S.; Li, X.; Chen, D.; Duan, Y.; Ji, H.; Zhang, L.; Chai, Q.; Hu, X. Understanding Land use/Land cover dynamics and impacts of human activities in the Mekong Delta over the last 40 years. *Glob. Ecol. Conserv.* **2020**, *22*, e00991. [CrossRef]
33. Luo, S.; Chui, T.F.M. Annual variations in regional mangrove cover in southern China and potential macro-climatic and hydrological indicators. *Ecol. Indic.* **2020**, *110*, 105927. [CrossRef]
34. Devi, K.; Sheikhi, A.; Cracknell, A.; Ching, H.; Pan, K.; Siong, C.; Nabilla, F. Satellite Images for Monitoring Mangrove Cover Changes in a Fast Growing Economic Region in Southern Peninsular Malaysia. *Remote Sens.* **2015**, *7*, 14360–14385.
35. Massod, H.; Afsar, S.; Bin, U.; Hassan, J. Application of Comparative Remote Sensing Techniques for Monitoring Mangroves in Indus Delta, Sindh, Pakistan. *Biol. Forum–Int. J.* **2015**, *7*, 783–792.
36. Purwanto, A.; Asriningrum, W. Identification of mangrove forest using multispectral satellite imageries. *Int. J. Remote Sens. Earth Sci.* **2019**, *16*, 63–86. [CrossRef]
37. Food and Agriculture Organization—FAO. *Forest Resources Assessment. Survey of Tropical Forest Cover and Study of Change Processes*; FAO forestry papers: Rome, Italy, 1996; p. 152.
38. Mas, J.; Lemoine-Rodríguez, R.; González-López, R.; López-Sánchez, J. Piña-Garduño, A.; Herrera-Flores, E. Land use/land cover change detection combining automatic processing and visual interpretation. *Eur. J. Remote Sens.* **2017**, *50*, 626–635. [CrossRef]
39. Ramírez, M.; Zubieta, R. *Análisis Regional y Comparación Metodológica del Cambio en la Cubierta Forestal en la Región Mariposa Monarca. Reporte Técnico Preparado Para el Fondo Para la Conservación de la Mariposa Monarca*; Mexico, D.F. Instituto de Geografía, UNAM: México D.F., México, 2005; p. 521.
40. Pulighe, G.; Baiocchi, V.; Lupia, F. Horizontal accuracy assessment of very high resolution Google Earth images in the city of Rome, Italy. *Int. J. Digit. Earth* **2015**, *9*, 342–362. [CrossRef]
41. Congalton, R.; Green, K. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*, 3rd ed.; Taylor & Francis: Boca Raton, FL, USA, 2019; p. 347.
42. Tilahun, A.; Teferie, B. Accuracy Assessment of Land Use Land Cover Classification using Google Earth. *Am. J. Envi-Ronmental Prot.* **2015**, *4*, 193–198. [CrossRef]
43. Aldwaik, S.; Pontius, R. Intensity analysis to unify measurements of size and stationarity of land changes by interval, category, and transition. *Landsc. Urban Plan.* **2012**, *106*, 103–114. [CrossRef]
44. Rwanga, S.; Ndambuki, J. Accuracy Assessment of Land Use/Land Cover Classification Using Remote Sensing and GIS. *Int. J. Geosci.* **2017**, *8*, 611–622. [CrossRef]
45. Kraff, N.; Wurm, M.; Taubenböck, H. Uncertainties of Human Perception in Visual Image Interpretation in Complex Urban Environments. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* **2020**, *13*, 4229–4241. [CrossRef]
46. Alava, J.; Saavedra, M.; Arosemena, X.; Calle, M.; Vinueza, C.; Jiménez, P.; Carvajal, R.; Vargas, H. Distributional records and potential threats to the Common (Mangrove) Black Hawk (*Buteogallus anthracinus subtilis*) in southwestern Ecuador. *Boletín SAO* **2011**, *20*, 18–28.
47. Centro de Levantamientos Integrados de Recursos Naturales por Sensores Remotos—CLIRSEN. *Estudio Multitemporal de Manglares, Camaroneras y Áreas Salinas de la Costa Ecuatoriana, Mediante Información de Sensores Remotos*; Programa de Manejo de Recursos Costeros, CLIRSEN: Quito, Ecuador, 1990; p. 40.
48. Romero, N. Neoliberalism and shrimp industry in Ecuador. In *Letras Verdes. Revista Latinoamericana de Estudios Socioambientales, FLACSO*; Facultad Latinoamericana de Ciencias Sociales FLACSO Ecuador: Quito, Ecuador, 2014; pp. 55–78.
49. Sonnenholzner, S.; Massaut, L.; Saldías, C.; Calderón, J.; Boyd, C. Case studies of Ecuadorian shrimp farming. In *Report Prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment*; Network of Aquaculture Centres: Bangkok, Thailand, 2002; p. 21.
50. Hamilton, S.; Lovette, J. Ecuador's Mangrove Forest Carbon Stocks: A Spatiotemporal Analysis of Living Carbon Holdings and Their Depletion since the Advent of Commercial Aquaculture. *PLoS ONE* **2015**, *10*, e0118880. [CrossRef] [PubMed]
51. López, F. Mangrove Concessions: An Innovative Strategy for Community Mangrove Conservation in Ecuador. In *Threats to Mangrove Forests. Coastal Research Library*; Makowski, C., Finkl, C., Eds.; Springer: Cham, Switzerland, 2018; Volume 25, pp. 557–578.
52. Cámara Nacional de Acuacultura. Estadísticas. Available online: https://www.cna-ecuador.com/estadisticas/ (accessed on 28 September 2021).
53. Krauss, K.; McKee, K.; Lovelock, C.; Cahoon, D.; Saintilan, N.; Reef, R.; Chen, L. How mangrove forests adjust to rising sea level. *New Phytol.* **2014**, *202*, 19–34. [CrossRef] [PubMed]
54. McNally, C.; Uchida, E.; Gold, A. The effect of a protected area on the tradeoffs between short-run and long-run benefits from mangrove ecosystems. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 13945–13950. [CrossRef] [PubMed]

55. Jia, M.; Liu, M.; Wang, Z.; Zhang, Y.; Mao, D.; Ren, C.; Cui, H. Evaluating the Effectiveness of Conservation on Mangroves: A Remote Sensing-Based Comparison for Two Adjacent Protected Areas in Shenzhen and Hong Kong, China. *Remote Sens.* **2016**, *8*, 627. [CrossRef]
56. Jia, M.; Wang, Z.; Zhang, Y.; Mao, D.; Wang, C. Monitoring loss and recovery of mangrove forests during 42 years: The achievements of mangrove conservation in China. *Int. J. Appl. Earth Obs. Geoinf.* **2018**, *73*, 535–545. [CrossRef]
57. De Lacerda, L.; Ward, R.; Pinto, M.; De Andrade, A.; Borges, R.; Ferreira, A. 20-Years Cumulative Impact from Shrimp Farming on Mangroves of Northeast Brazil. *Front. For. Glob. Chang.* **2021**, *4*. [CrossRef]
58. Kamali, B.; Hashim, R. Mangrove restoration without planting. *Ecol. Eng.* **2011**, *37*, 387–391. [CrossRef]
59. Beck, M.; Heck, N.; Narayan, S.; Menéndez, P.; Torres-Ortega, S.; Losada, J.; Way, M.; Rogers, M.; McFarlane-Connelly, L. *Reducing Caribbean Risk: Opportunities for Cost-Efective Mangrove Restoration and Insurance*; Nature Conservancy: Arlington, VA, USA, 2020.
60. World Wildlife Fund—WWF. Northern South America: Coastal Ecuador. Available online: https://www.worldwildlife.org/ecoregions/nt1418 (accessed on 1 October 2021).
61. Comisión Nacional Para el Conocimiento y Uso de la Biodiversidad—CONABIO. *Los Manglares de México: Estado Actual y Establecimiento de un Programa de Monitoreo a Largo Plazo: 1ra. Etapa.*; Informe Final del Proyecto DQ056: Mexico City, Mexico, 2007; p. 47.
62. Spalding, M.; Mclvor, A.; Tonneijck, F.; Tol, S.; Van Eijk, P. Mangroves for coastal defense. Guidelines fos coastal managers & policy makers. *Wetl. Int. Nat. Conserv.* **2014**, *42*.
63. Arifanti, V.; Novita, N.; Subarno; Tosiani, A. Mangrove deforestation and CO_2 emissions in Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *874*, 012006. [CrossRef]
64. Ministerio del Ambiente, Agua y Transición Ecologíca—MAATE. Plan Nacional Para la Conservación del Manglar se Desarrolló en Machala. Available online: https://www.ambiente.gob.ec/plan-nacional-para-la-conservacion-del-manglar-se-desarrollo-en-machala/ (accessed on 30 September 2021).
65. Badola, R.; Barthwal, S.; Hussain, S. Attitudes of local communities towards conservation of mangrove forests: A case study from the east coast of India. *Estuar. Coast. Shelf Sci.* **2012**, *96*, 188–196. [CrossRef]
66. Susilo, H.; Takahashi, Y.; Yabe, M. The opportunity cost of labor for valuing mangrove restoration in Mahakam Delta, Indonesia. *Sustainability* **2017**, *9*, 2169. [CrossRef]
67. Sudtongkong, C.; Kong-oh, S.; Intacharoen, P. Geographical information system assessment of mangrove area changes under state versus community management in two communities in Trang province, southern Thailand. *Maejo Int. J. Sci. Technol.* **2013**, *7*, 85–95.
68. Friess, D.; Rogers, K.; Lovelock, C.; Krauss, K.; Hamilton, S.; Yip, S.; Lucas, R.; Primavera, J.; Rajkaran, A.; Shi, S. The State of the World's Mangrove Forests: Past, Present, and Future. *Annu. Rev. Environ. Resour.* **2019**, *44*, 89–115. [CrossRef]